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A
COMPEND OF GEOLOGY

BY

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OF CALIFORNIA; AUTHOR OF "ELEMENTS OF GEOLOGY," ETC.

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PREFACE.

In preparing this little work for the schools I have kept constantly in view two ends: 1. I have tried to make a book which shall interest the pupil, and at the same time convey real scientific knowledge. 2. I have tried, as far as possible, to awaken the faculty and cultivate the habit of observation, by directing the attention of the pupil to geological phenomena occurring and geological agencies at work *now* on every side, and in the most *familiar things*. By the former I hope to awaken a true scientific appetite; by the latter, to cultivate the habits necessary to satisfy that appetite.

JOSEPH LE CONTE.

BERKELEY, CALIFORNIA, *September*, 1884.

PREFACE TO THE REVISED EDITION.

Although a work so elementary as this—embodying only the most general principles of geology—does not require so frequent revision as a more advanced work, yet geology is so rapidly advancing a science that even general statements must, from time to time, be modified. Especially is it necessary that new and better illustrative figures should be used.

In this revised edition I have not changed the general plan of the work as already explained in the preface of the previous edition, but have only made such modifications and additions as seemed necessary to bring it up to the present condition of science. Among these additions, certainly not the least important are the beautiful restorations of vertebrate skeletons and photographs of natural objects for which I am indebted to Professors Marsh, Dean, Williston, and Scott. I wish hereby to thank these gentlemen for their hearty coöperation. Acknowledgment is due also to the American Museum of Natural History, New York, N. Y., for the photograph of the Great Barrier Reef, shown on page 97.

JOSEPH LE CONTE.

BERKELEY, CALIFORNIA, *January*, 1898.

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GEOLOGY.

INTRODUCTION.

Definition of Geology.—Geology is the science which treats of the *past* conditions of the *earth* and of *its inhabitants.* It is, therefore, a history of the earth. It is closely allied to physical geography, but differs in this: Physical geography treats only of the *present* forms of the earth's features; geology also, and mainly of their gradual formation, or *evolution from former conditions.* It is also closely allied to natural history, but differs in this: Natural history is concerned only with the *present* forms and distribution of animals and plants, while geology is chiefly concerned about *previous forms* and distribution, and their changes to the present forms and distribution. In a word, geography and natural history are concerned about how things *are;* geology, about *how they became so.*

Cultivates Habit of Observation.—We have said geology treats of the history of the past conditions of the earth and its inhabitants. The evidences of the past conditions are found in its present structure. But, to understand this structure, we must observe the manner in which similar structure is formed *now* under our eyes. Thus, observation of *causes now in operation* constitutes the only solid foundation of geology. Fortunately, the processes by which structure is now being formed may be observed everywhere; and the structures which have been thus formed in earlier times may be observed in very many places, if we know how to look for them. Thus geology, perhaps more than any other science, cultivates the habit of field-observation ; not, indeed, that minute observation required by mineralogy or botany, but that wider observation which gives interest to mountain-travel or even to rambles over the hills in our vicinity. It cultivates also, in an eminent degree, the habit of tracing effects to their causes—for the question ever present to the geologist is, "*How came it so?*"

Great Divisions of Geology.—We have said that the history of the earth is recorded in its structure, and that structure is understood by study of causes or processes now in operation. We have thus outlined the great divisions of geology, and the order in which they must be studied. We must study, first of all, causes and processes now in operation about us everywhere, producing structure. This is called *dynamical geology*. Next, we must study the rocky structure of the earth to as great a depth as we can, and apply the previously acquired principles in its interpretation ; for this structure has been produced by similar processes acting through all previous time. This is called *structural geology*. Only after this shall we be prepared to take up the history of the changes through which the earth has passed ; for this history is revealed in structure. This is called *historical geology*.

PART I.

DYNAMICAL GEOLOGY.

As already said, this part treats of agencies now in operation producing structure. These are best treated under four heads—viz., *atmospheric, aqueous, organic*, and *igneous* agencies. The same agencies have operated from the beginning, though probably with different degrees of activity. Their accumulated effect, through inconceivable ages, is the present structure of the earth. We observe these operations *now*, in order to understand the effects of their operation *then*.

CHAPTER I.

ATMOSPHERIC AGENCIES.

Origin of Soil.—If we dig into the earth anywhere, at a certain depth, greater in some places than in others, we find *rock*. How was the earthy soil formed ? Perhaps some imagine that it is an original clothing intended to cover the rocky nakedness of the new-born earth. But the very first lesson to be learned by the study of geology is that all things that we see, even the most enduring—such as hills, mountains, rocks, etc.—have *become* what they are, usually by a *slow process.*

Now, soils are no exceptions. All soil is formed by a disintegration or *rotting down* of rocks. Sometimes the soils *remain* resting on the rocks from which they were formed ; sometimes they are *removed* to another place, as, e. g., from hillsides to bottom-lands ; sometimes they are *carried* by streams to *great distances,* and deposited as sediments, and again raised as land ; but in all cases they are formed in the same way—viz., by the rotting down of rocks under the slow action of the atmosphere.

The active ingredients of the air in this process are oxygen, carbonic acid (carbon dioxide), and water, as vapor or as moisture. Now, rain-water contains in solution both oxygen and carbon dioxide. Therefore, rain-water, wetting the surface and penetrating the cracks of rocks, is the great agent in the formation of soil.

Proofs of this Origin of Soils.—The proofs of this mode of formation are clearest in those cases in which the soil still rests on the rock from which it was made. Unfortunately this is rare in the northern part of our country, where the soil has been nearly everywhere *shifted* during a period which we shall hereafter describe as the *Drift period.* But in the southern part of the United States, on all the hillsides and mountain-tops, the soil has been undisturbed for ages, and the evidence is complete, and may be observed by any one. If, for example, we note carefully the sections made by railroad and well diggings, we shall see at the top *perfect soil,* perhaps red; a little deeper it becomes lighter colored and coarser grained; then it begins to look like rotten rock; and, finally, by insensible degrees, it passes into sound rock. The evidence is still more complete if, as is often the case, the rock is traversed by a *quartz-vein.* In such a case we can trace the quartz-vein through the sound rock, and upward through the rotten rock, the imperfect soil, and the perfect soil, to the surface, where it may usually be traced over hill and dale as white fragments lying on the surface. The reason is this: Quartz is a mineral which will not disintegrate under atmospheric agency; therefore it remains sound, while all the rest of the rock is changed into soil (Fig. 1).

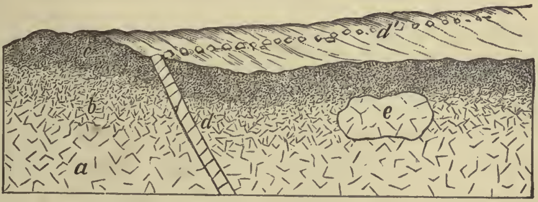

FIG. 1.—Section and perspective view (ideal). *a*, sound rock; *b*, rotten rock; *c*, perfect soil; *d*, quartz-vein; *d′*, same, outcropping on surface; *e*, mass of more resistant rock imbedded in soil.

Sometimes a rounded mass of sound rock, *e*, is seen imbedded in the soil. This is only a harder piece of rock, which has resisted disintegration, while the rest has yielded. These are called bowlders of disintegration.

It is not always, even in lower latitudes, that we find this gradation between soil and rock. Often perfect soil is found to rest on sound rock, with sharp limit between. In all such cases there has been shifting of the soil. In northern latitudes (37°–40° northward), as already stated, the soil nearly everywhere rests on sound rock, and often the underlying rock is smooth and polished. We shall explain this hereafter. But even in the Northern States, if one will notice closely, he will see the process of soil-making going on. Rock-fragments, which were once angular, become rounded by rotting of the corners. Cliffs, by their crumbling, gather piles of rock-fragments and earth (*talus*) at their bases (Fig. 2). The pupil ought to observe these things habitually, as it is on just such observation of simple things that true science rests.

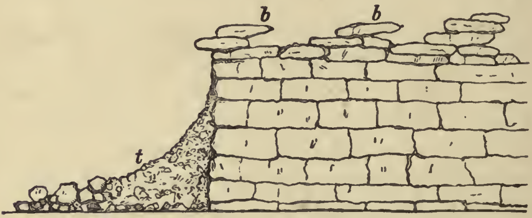

FIG. 2.—Cliff, showing talus, *t*, and bowlders of disintegration, *b*, *b*.

Depth of Soil.—Since soil is constantly carried away by washing of rain, as will be more fully explained in the next chapter, it is evident that there are two opposite processes here to be considered, viz., soil-formation and soil-removal. The depth of the soil will depend on the relation of these two to each other. More definitely, the depth of the soil depends partly upon the kind of rock (for this affects the rate of formation), and partly on the slope (for this affects the rate of removal). On high slopes the rock is *bare* (Fig. 3, *a*), not because there is no soil formed, but because it is removed as fast as formed.

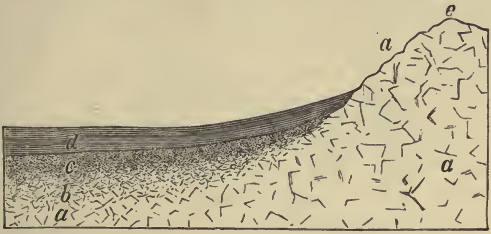

Fig. 3.—*a*, sound rock; *b*, rotten rock; *c*, soil formed in place; *d*, soil shifted from *e*.

On flat lands, near high slopes, the soil is deep (Fig. 3, *b*), because not only is it formed here in place, but the washings from above are added.

Rate of Disintegration.—If rocks were solid, so that the agents of decomposition could act only on the surface, the rate would be inconceivably slow, but all rocks are affected with joints in several directions, by which the mass is divided into more or less separable blocks, so that a cliff looks something like a wall of regularly piled blocks without cement (Fig. 2). Water, therefore, penetrates to great depths, attacking the surface of every block. Also, every block is itself affected throughout with capillary fissures, through which water penetrates to every part (quarry-water of stone-cutters). Thus, the rocky crust of the earth is affected by disintegrating agencies to very great depths—though, of course, most rapidly at the surface.

Bowlders of Disintegration.—All over the Northern States are found scattered rock-masses (bowlders), lying on the surface. If we examine these, we shall usually find that they are entirely different from the country-rock. They have been brought from a distance—how, we shall explain hereafter. We have nothing to do with these now. But in the Southern States also, in many places, are found huge, isolated masses, lying on the surface, and even sometimes forming rocking stones (Fig. 4). If we examine these, we find that they are of the same material as the country-rock. They have been formed *in place.* In the general disintegration of rock, and formation and removal of soil, these have resisted, because harder than the rest. Nothing is more interesting than thus to trace the configuration of the surface of the country to unequal resistance to atmospheric agencies.

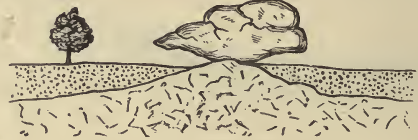

FIG. 4.

Explanation of Rock-Disintegration.—If we take a piece of old and very hard mortar, and pour on it a little hydrochloric acid, it quickly breaks down into sand, wet with a solution of calcium chloride. The explanation is simple. Mortar consists of grains of sand cemented into a mass by hydrate or carbonate of lime. The acid dissolves the lime-cement, and the mass falls to powder. Now, mortar is really artificial stone, and nearly all rock is constituted in a similar manner, i. e., consists of particles cemented together. In all rock some parts are soluble in atmospheric water, and some are not. Under the long-continued action of this agent, therefore, the soluble parts are dissolved, and the mass breaks down into a powder, or dust of the insoluble parts, wet with a solution of the soluble parts. The main difference between the experimental and the natural case is, that in one the process is rapid, and in the other extremely slow.

Examples.—One or two examples will make this plain :

1. *Sandstone* is a rock made up of grains of sand cemented into a mass, sometimes by lime carbonate, sometimes by silica. Under the slow action of atmospheric water the cement is dissolved, and the rock crumbles into sand, moistened with a solution of lime carbonate, if this be the cement. 2. *Granite* and gneiss and many other igneous and metamorphic rocks, such as are found on the eastern slope of the Appalachian Chain everywhere, are an aggregation of four minerals, viz., *quartz, feldspar, mica,* and *hornblende.* In coarse granite these can be easily seen with the naked eye. The bluish glassy specks are quartz; the opaque white, or rose-color, are feldspar; the glistening scales are mica; and the black spots, hornblende.* The whole rock may be regarded as grains of quartz, mica, and hornblende cemented into a mass by feldspar. Now, quartz is not at all, and mica very slightly, affected by atmospheric water; but the feldspar and hornblende are slowly changed into clay, which, in the case of hornblende, is red, from the presence of iron. Thus, the whole rock rots down to a clay soil, usually red, in which are disseminated grains of quartz and scales of mica, the whole moistened with water, containing in solution a little potash derived from the feldspar. This is the commonest of all soils. 3. *Slates* and *shales* are clays hardened into rock by some cement such as lime or silica. When the cement is dissolved the rock crumbles into a clay soil. 4. A *pure limestone* like marble makes no soil because it is all soluble, but most limestones are mixed with clay or sand. When the lime is dissolved the result is a limy clay or limy sand.

Mechanical Action of Air; Frosts.—The soil-formation, above explained, is a chemical process, but, in cold climates and mountain-regions, atmospheric water acts also mechanically and very powerfully in rock-disintegration. Water penetrating the joints, and freezing, expands with such force that the rocks are riven asunder; and then, penetrating again into the capillary fissures and freezing, these blocks are in their turn broken into smaller fragments, until the whole crumbles to dust.

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* These minerals ought to be shown the pupil, both separately and as aggregated in a specimen of coarse granite.

Wind.—Again, loose earth, sand, and dust, especially in dry climates, are carried by winds, and sometimes accumulate in large quantity and form a peculiar soil. Thus, the sands of Sahara are in some places encroaching on the fertile lands of Egypt. Thus, also, sea-sands are often carried inland from shore, and cover up and destroy fertile lands. The sand-hills to the west of San Francisco are made in this way. The phenomena of sand-dunes may be observed in many places along the coasts of nearly all countries. Some geologists think that in the interior of dry countries, like Asia or the western part of our own country, soil of great thickness has been formed by accumulation of dust.

CHAPTER II.

AQUEOUS AGENCIES.

Aqueous and atmospheric agencies are so closely connected that many treat them together under the one head of *leveling* agencies. Water, as atmospheric moisture or as rain, soaking into the earth, is the chief agent of *soil-making;* but water, falling more abundantly, runs off the surface, and is also the chief agent of *soil-removal.* In the one case it acts as a chemical, in the other as a mechanical, agent. The agency of water in soil-making we treated under *atmospheric,* its agency in soil-removal belongs to *aqueous,* agencies. The one, acting at all times and in all places, its effects are obscure and inconspicuous; the other, acting occasionally and concentrating its power on particular places, its effects are easily observed and better understood. Nevertheless, the aggregate effects of the one must be equal to those of the other, for the former prepares the way for the latter. Aqueous agencies have little effect upon rocks unless they have been first rotted down to soils.

Although the agency of water is mainly mechanical, yet there is a chemical agency of water other than that of soil-making. The agency of water may therefore be divided into mechanical and chemical. The *mechanical* agency is best treated under the three heads of *rivers, ocean,* and *ice,* and each of these again in cutting away, in carrying, and in throwing down again, or in *erosion, transportation,* and *deposit.* The chemical agency we shall consider under the two heads of chemical deposits in *springs* and in *lakes:*

AQUEOUS AGENCY.	Mechanical..	Rivers, erosion, transportation, deposit.
		Ocean, “ “ “
		Ice, “ “ “
	Chemical....	Springs, chemical deposits in,
		Lakes, “ “

SECTION I.—RIVERS.

Atmospheric or *meteoric* water falls on land as rain. A portion sinks into the earth, and, after a longer or shorter subterranean course and doing its appropriate work of rock-disintegration and soil-making, comes up again to the surface as springs. Another portion runs off the surface, cutting and carrying away the soil everywhere. Quickly, however, it gathers into *rills* and cuts furrows, these rills uniting into streamlets and cutting gullies. The streamlets, uniting with each other, and with water issuing from springs, form mountain-torrents, and cut out great ravines, gorges, and cañons. Finally, the torrents, emerging on the plains from their mountain home, form great rivers, which deposit their freight of gathered earth and rock-fragments in their courses, and finally in the sea or lake into which they empty. Such is a condensed history of the course and work of water from the time it falls as rain until it reaches the ocean from which it came. All of this we include under *river-agency*. It may be defined as the work of *rain and rivers,* or the work of *circulating meteoric water*. All that follows on this subject will be but an expansion of the condensed statement given above, and much of it may be observed by any one who does not commit the mistake of thinking things insignificant because they are common.

1. *Erosion of Rain and Rivers.*

The rain which falls on land-surface may be divided into three parts: One part runs immediately from the surface, producing universal *rain-erosion* and the *muddy* *floods* of the rivers. Another part sinks into the earth, and, after doing its appointed work of soil-making, reappears on the surface as springs, and forms the ordinary flow of rivers in dry times. This part joins the surface drainage, and together they concentrate their work along certain lines, and thus produce *stream-erosion.* A third portion never reappears on the surface, but finds its way, by subterranean passages, to the sea.

By the continued action of rain and rivers all lands (except some rainless deserts) are being cut away and carried to the sea. Every one, each in his own vicinity, may see this process going on. The soil of the hillsides is everywhere being washed away by rain, and carried off in the muddy streams. At what average rate is this washing process going on? This is a question of extreme importance.

NB **Average Rate of Erosion.**—By observations made on rivers in all parts of the world it has been estimated that all land-surfaces are being cut away at a rate of about one foot in 3,000 to 5,000 years. The Mississippi cuts down its whole drainage-basin one foot in 5,000 years, the Ganges one foot in 2,000 years. Some rivers cut still more rapidly, but most less rapidly than these. The rate differs in different parts of the same basin. In mountain-regions the rate is at least three times the average given above, and on steeper slopes still greater. On the lower plains the erosion is small, and in many places there is deposit instead of erosion. Making due allowance for all these variations, it is probable that all land-surfaces are being cut down and lowered by rain and river erosion at a rate of one foot in 5,000 years. At this rate, if we take the mean height of lands as 1,200 feet, and there be no antagonistic agency at work raising the land, all lands would be cut down to the sea-level and disappear in 6,000,000 years.

This universal cutting away of land-surfaces we have divided for convenience into two parts, which, however, graduate completely into each other—viz., *rain-erosion* and *stream-erosion:* the one is universal, but small and inconspicuous in any one place; the other is confined to water-channels, but works with concentrated and conspicuous effects. The one may be compared to a universal *sand-papering,* the other to the action of the *graver's tool,* cutting ever deeper along the same lines. Of the two, the general rain-erosion, though less conspicuous, is probably far the greater in aggregate amount. They cooperate in cutting away the land, and, if unopposed, would finally destroy it. *Pure water,* however, has comparatively little effect. Its graving-tools are the sand, gravel, pebbles, and rock-fragments, which it carries along in its course.

Conspicuous Examples of Stream-Erosion.—The effects of erosion are most conspicuously seen in waterfalls, ravines, gorges, and cañons; but also, in less degree, on every hillside, and in every furrow and gully.

Waterfalls; Niagara.—The Niagara Falls and gorge are an instructive example of stream-erosion, because the effects are easily observed from year to year.

General Configuration of the Country.—Lake Erie is situated on a nearly level plateau, several hundred feet above a similar plateau, on which is situated Lake Ontario. The plateaus are separated by an almost perpendicular cliff, running east and west, near Lake Ontario. The Niagara River runs out of Lake Erie, and on the Erie plateau, fifteen to eighteen miles, then drops, by a perpendicular fall, into a narrow gorge, with nearly perpendicular sides, and runs in the gorge for seven miles, and then emerges on the Ontario plateau just before emptying into that lake. Fig. 5 is an ideal section through the middle of the river, and showing these facts. The light lines show the cliffs on the other side of the gorge.

Recession of the Falls.—Ever since their discovery, 200 years ago, the falls have steadily worked their way back toward Lake Erie. The rate of recession has been estimated at one to three feet per annum. The cause is easily perceived. The strata at the falls consist of solid limestone, represented in the figure by the jointed structure, underlaid by softer shale. The force of the dashing water cuts away the soft shale and undermines the limestone, causing it to project as overhanging rocks, which fall from time to time into the abyss below. Thus the falls work backward, but remain perpendicular.

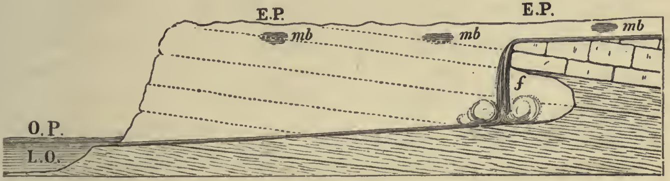

FIG. 5.—Section of Niagara Falls and gorge. O.P., Ontario plateau; E.P., Erie plateau; L.O., Lake Ontario; *f*, fall; *mb*, stratified mud-banks.

Gorge formed by Recession.—There can be no doubt that the whole gorge has been formed in this way; that the river once fell over the cliff which runs across its course near Lake Ontario, and then worked its way back to its present position; and the work is still going on. The general configuration of the country suggests this origin even to the casual observer, and close examination entirely confirms it. It is a familiar fact that stratified mud-banks are found in spots along the margins of all rivers, evidently formed by deposits from the river. These stratified muds often contain the shells of the mussels which inhabit the river. Now, in several spots (*mb*) along the top of the gorge-cliff, from the falls to Lake Ontario, are found such stratified mud-deposits containing shells. The deposits were evidently made when the river ran at that level.

Time.—Several attempts have been made to estimate the time occupied in this process. Mr. Lyell estimated it at 35,000 years.* A large part, if not the whole of this time, belongs to the present geological epoch, and was probably witnessed by early man.

Other Falls.—Many other perpendicular falls have receded in a similar way and given rise to similar gorges. The most remarkable of these are the *Falls of St. Anthony*. The Mississippi River, at Fort Snelling (mouth of the Minnesota River), is traversed by an escarpment which separates a higher from a lower plateau. The river runs on the upper plateau as far as Minneapolis, then drops, by a nearly perpendicular fall, into a gorge one hundred feet deep, runs in this gorge eight miles, and then emerges on the lower plateau at Fort Snelling. Here, again, we have the upper plateau capped by a hard limestone, underlaid by a soft sandstone. Here, also, the wearing away of the underlying sandstone causes the limestone to project in overhanging tables which fall from time to time into the chasm below, and so the fall works backward. There is no doubt that the Mississippi at one time fell over the escarpment at Fort Snelling, and has worked its way back to its present position, and that this all took place during the present geological epoch, and while man inhabited the continent. Professor Winchell has estimated that, at its present-rate recession, it would take not more than 8,000 years to accomplish the work.

Minnehaha River is a tributary running into the Mississippi about six miles below the falls. It therefore, at one time, fell into the gorge. It has now worked itself back about two miles, and forms the beautiful "Minnehaha Falls," made celebrated by their description in Longfellow's "Hiawatha."

The Columbia River, where it breaks through the Cascade Range, has cut a gorge fifty miles long and 1,000 to 3,000 feet deep. All the tributaries which run into the river at this point have cut deep side gorges, headed by perpendicular falls. Some of the most exquisite falls are here nestled among the hills in these almost inaccessible gorges. The country rock is a very hard but much jointed lava, underlaid by a softer cement-gravel. The falls have eaten out the gravel and undermined the lava, which from time to time tumbles into the chasm as blocks that are carried away by the stream. In this way the falls have worked back about two miles.

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* Later estimates make it about 11,000 years.

Yosemite Falls.—Most perpendicular falls have been made by recession, as explained above, but this is not true of all. The Yosemite Falls (of which there are six, varying in height from 400 to 1,600 feet) have not perceptibly receded. This is because the granite is very hard, and the time too short (probably only a few thousand years), since the valley was filled with ice (page 394).

Ravines, Gorges, Cañons.—These are found in all countries, especially in mountainous and high-plateau regions. They are always or nearly always formed by running water, although in some cases their places are determined by fractures of the earth's crust (page 229). They are gullies on a large scale. In the Appalachian Chain the most striking examples are the Hudson River gorge in New York, the Tallulah gorge in Georgia, and the French Broad gorge in North Carolina. But it is in the western part of the continent that the finest examples are seen. Nowhere in the world are they on a grander scale, more evidently due to water alone, or more recent in origin. As we are studying "causes now in operation," they are the most instructive examples to be found anywhere.

In **California** there was, even since middle geological times, an old river-system different from the present. This will be explained more fully hereafter (page 395). These old river-valleys were filled up with river-gravel, and finally obliterated by lava-flows not long before the advent of man. The displaced rivers have since that time cut new channels, far deeper than the old, so that the old lava-covered channels are high up on the present divides (Fig. 6). Thus, in very recent geological times—i. e., in the Quaternary and present epochs—water has cut at least 2,000 feet deep in hard slate-rock.

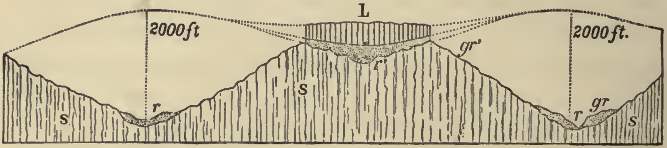

Fig. 6.—Section across old and new river beds of California. *r*, *r*, **new river beds;** *r'*, **old river bed;** *gr*, **gravels of present rivers;** *gr'*, **old river gravels;** *dotted line*, **old configuration of surface.**

We have selected these cases because of the plain evidence of recent work, but the whole western slope of the Sierra is trenched with enormous ravines, 3,000 to 6,000 feet deep, although the history of some of them is longer than those spoken of above. For example, commencing north and going southward, we have the Columbia River, with its gorge 3,000 feet deep in hard lava. The branches of the Feather, Yuba, and American Rivers have cut gorges 2,000 to 3,000 feet deep in hard slate. These have the structure represented by Fig. 6, and have been cut wholly in very recent geological times. The Tuolumne and Merced Rivers have cut gorges 3,000 to 5,000 feet deep, the famous Hetch-hetchy and Yosemite Valleys being in the course of these. King's River Cañon is 7,000 feet deep, in hard granite.

Plateau Region.—But the most wonderful gorges or cañons in the world are found in the high-plateau region—i. e., the region between the Colorado and Wahsatch Mountains, and drained by the Colorado River. This region is 6,000 to 8,000 feet high, and consists of nearly level strata, which have been cut into by the Colorado and its tributaries in such wise that the whole river system of the country runs far below the general level. The Grand Cañon of the Colorado is 300 miles long and 3,000 to 6,000 feet deep, and all its tributaries come in by side cañons of almost equal depth (Fig. 7).

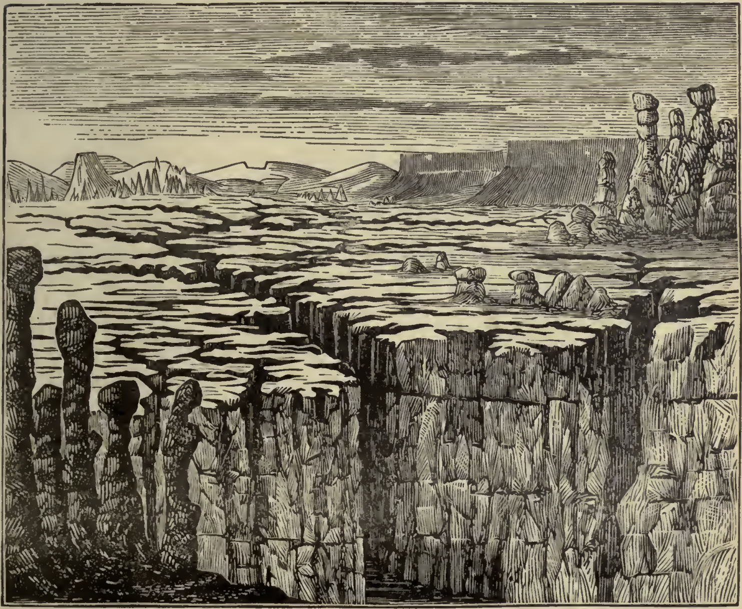

FIG. 7.—View of Colorado Cañon and its tributaries, with erosion-columns and mesas in the distance.

Besides this prodigious stream cutting, the general rain-erosion has been here upon an equally grand scale. Many thousands of feet have been carried away over the whole area of about 100,000 square miles or more. This is shown by the isolated peaks and tables of level strata scattered about, and still better by the succession of cliffs shown in

Fig. 156 (page 250), as will be more fully explained hereafter.

Time.—The time during which the whole of this enormous work was done is but a small portion of the geological history. It commenced in Middle Tertiary (page 383), continued to the present time, and is still going on.

Pot holes.—If we examine the bare rocky beds of swift streams in mountain regions, we often find deep holes with vertical walls like small rock wells. In their bottoms we are sure to find gravel and a good many rounded *pebbles.* These are called *pot holes.* They are formed thus: Swift streams form whirling eddies, in which sand, gravel, and rock fragments carried by the stream are whirled about in the same spot until they hollow out these holes, while the fragments themselves are rounded into pebbles in the process. These become signs of old river beds where rivers no longer exist.

2. *Transportation and Distribution of Sediments.*

River agency, it will be remembered, is taken up under three heads. We have already taken up one—Erosion. The other two are best taken up together, as Transportation and Distribution of Sediments.

Transporting Power of Water.—Every one is familiar with the fact that running water carries along materials of different degrees of fineness, but the rate at which the carrying or lifting power increases with the velocity is almost incredible to those who have not investigated the subject. It is found that the size or weight of the separate particles or fragments movable by running water increases at the enormous rate of the sixth power of the velocity of the current. Thus, if the velocity of a current be doubled, it can carry a stone sixty-four times as great as before; if it be increased ten times, it can carry a stone 1,000,000 times as great as before. We can thus easily understand the prodigious power of mountain-torrents when swollen by heavy rains.

It follows from the above that, if a stream be carrying all it can, the least checking of its velocity will cause abundant deposit, and the least increase of its velocity will cause it to take up again what it had previously deposited—i. e., it will scour its bed and banks.

Sorting Power of Water.—If we take a handful of earth and throw it into a deep basin, and, after allowing it to settle, pour off the water and examine the sediment, we shall find that it is neatly sorted, the coarser particles being at the bottom, and above this finer and finer, until a very fine, smooth mud forms the top. The earth will be still better sorted if we throw it into *running* water. In this case the coarser will drop first, i. e., higher up, and the finer lower and lower, until only the finest will be carried far down the stream. This is especially the case if the velocity decreases as we go down-stream, as is usually the case in natural streams. Thus, pebbles are found in torrent-beds, and fine mud in lower parts of streams.

Stratification.—If we examine carefully the mud or sand of a river-bank or lake-margin, we shall always find them *stratified,* i. e., in layers of slightly different color and grain. This is easily explained by the sorting power of water. If the water be *still,* as in a lake or pond, then with every rain earth is brought in, and by settling *is sorted,* the finest falling last. Thus the coarse material of one rain falls on the fine of the previous rain, and every rain is marked by a separate layer. In *rivers,* the same result follows, but the explanation is a little different. The velocity of the current is changing from day to day on account of the varying supply of water. The stream-lines also are continually shifting from side to side. Thus the velocity at any one point is all the time changing, and therefore the character of the material deposited is also changing from day to day, and even from hour to hour—now coarser, now finer—and a very distinct, though often irregular, *stratification is the result.*

General Law.—We may therefore state it as a general law that *all deposits in water,* whether still water, as lakes and seas, or running water, as rivers, *are stratified,* and, conversely, that *all stratified materials,* wherever we find them, whether near water or high up on the tops of mountains, and in whatsoever condition we find them, whether as sands and muds or as hard stone, if the stratification be a true stratification, i. e., the result of sorted material, *have been deposited in water.* Upon this very simple law nearly the whole of geological reasoning is based. It is important, therefore, that every one should habitually observe the phenomena described above, not only in lakes and rivers but in shower-rills and pools. We are now in position to explain all the phenomena of rivers.

1. *Final Effect of Erosion of Rain and Rivers.*

There is a certain slope of a river-bed, depending on the amount of sediment carried, at which the river neither cuts nor deposits. This is called its *base-level of erosion.* Every river is seeking this level. If above it, it seeks to reach it by cutting; if below it, by building up by sedimentation. As soon as the river reaches this level, it rests, so far as down-cutting is concerned, but now begins to sweep from side to side, widening its channel. Meanwhile the side streams and rain-wash continue to cut down the divides. If this continues without interruption, the final result is a gently undulating land-surface with low divides and broad river channels. This is called a *Peneplain.* It means that the land has remained steady and the rivers have been working on it, *a long time.* It is *old topography.* If the land be now elevated by interior forces the rivers increase in velocity and begin cutting again and form deep cañons. These deep cañons are therefore characteristic of *new topography*—i. e., of a rising or newly risen land and of rivers far above their base-level and working hard to reach it. If on the other hand the land sinks, the rivers become more sluggish—they cease to cut and begin to build up by deposit. Thus river channels become delicate indicators of the movements of the earth's crust.

2. *Winding Course of Rivers.*

The winding course of rivers is the necessary result of the laws of currents. Streams do not find irregular channels to which they are forced to conform, but they make their own channels. If we straighten these channels, they will not remain straight. Some point will wear into a hollow. This will throw the stream to the other side, which will in like manner be worn, and thus the stream begins to meander. Now, if we examine any winding stream, we shall see that the swiftest current is on the outer part of the curve and the slowest on the inner side, or, in other words, the current is swifter than the average on the outer and slower than the average on the inner side of the bends. In the figure, the arrows show the line of swiftest current. Now, if the river is carrying all the sediment its average velocity can, it is evident that it will cut on its outer curve, where the velocity is greater than the average, and deposit and make land on the inner side, where the velocity is less than the average. Thus the outer curve is increased by erosion and the

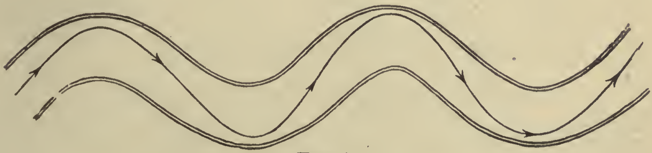

FIG. 8.

inner curve by deposit, and the winding tends ever to become greater and greater. This is most conspicuous in cases in which rivers run between mud-banks made by their own deposit. In such cases, the curves become greater and greater, until finally two contiguous curves cut into each other, the river straightens itself, and the old bend is thrown out and becomes a *lagoon* (*d*, Fig 9).

adjacent

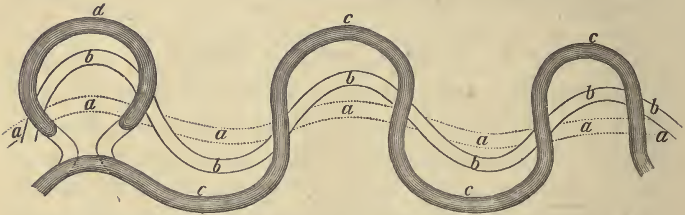

FIG. 9—*a*, *b*, *c*, successive stages in the winding course of a river.

Many such lagoons exist in all rivers which run through swamp-lands. Fig. 9 shows the process, and Fig. 10 is a portion of the lower Mississippi River showing the result.

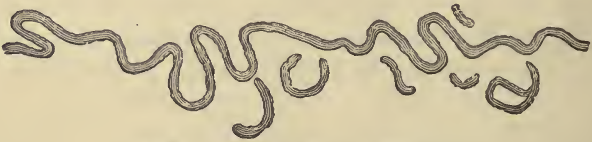

FIG. 10.—A portion of lower Mississippi.

3. *Flood-Plains and Their Deposits.*

Rivers usually rise in hilly or mountainous regions, and flow in the lower course through flat plains. In flood seasons, the velocity being checked by change of slope, the channels are no longer able to contain their waters, which therefore overflow portions of the flat lands on each side. *The area liable to overflow is called the flood-plain.* In case of great rivers draining interior continental basins, the flood-plains are very large. The flood-plain of the

Nile is the whole land of Egypt, for without the Nile the whole of Egypt would be a desert. Egypt is literally the daughter of Nilus. The flood-plain of the Mississippi extends from the mouth of the Ohio River to the Gulf—its area is 30,000 square miles.

Now, since great rivers always rise in mountain-regions, and since the general rain-erosion in such regions is very great, it is evident that in flood seasons they gather abundant sediment, and, when these muddy waters overflow, the checking of velocity causes abundant deposit all over the flood-plain. With every flood this deposit is renewed, and the stratum becomes thicker. Thus, the level of the flood-plain is built up by sedimentary deposit, without limit. In the Mississippi River the flood-plain deposit is about fifty feet thick. In the Nile it is forty to eighty feet thick.

Time.—On the flood-plain of the Nile stand the oldest monuments of civilization in the world. One of these (the statue of Rameses II), supposed to be 3,000 years old, has been covered about the base with sediment nine feet deep. The whole thickness of the Nile sediment at this point is forty feet—nine feet in 3,000 years would make forty feet in 13,330 years as the age of the Nile deposit. This is, of course, but a rough estimate. The rate may not have been uniform. But in any case the whole time belongs to the present geological epoch.

Levees, Natural and Artificial.—In rivers which regularly flood their plains we always find a sort of embankment on either side near the river, higher than the rest of the flood-plain, and consisting of coarser material. This is called the *natural levee* (Fig. 11, *l*, *l*). When the river is at full flood, *e*, *e*, the whole flood-plain is covered, but at half flood *d*, *d*, *d*, it is often divided into three streams, viz., the river channel and the back swamp on either side. The cause of the natural levee may be explained thus: The whole flood-plain is covered with water moving slowly seaward. Through the middle of this comparatively still water runs the swift current of the river-channel. Now, on the two sides of this swift current, just where it comes in contact with the stiller water, and is checked by it, there will be a line of abundant and coarser sediment.

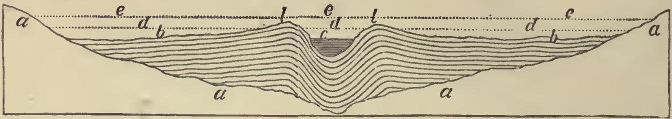

FIG. 11.—Ideal section of a flooding river. *a*, *a*, *a*, *a*, original bed; *b*, *b*, flood-plain; *l*, *l*, natural levees; *c*, low water; *d*, *d*, *d*, half flood; *e*, *e*, *e*, full flood.

Artificial Levees.—Natural levees can not restrain the floods of rivers, since they are made by such floods. By deposit, the bed of the river, the natural levees, and the back swamp, all rise together, maintaining their relative level. If, therefore, we desire to restrain the floods and reclaim the flood-plain, we must build artificial levees upon the natural ones. This interference modifies greatly the phenomena of deposit. The river continues to build up its bed as before, and would in time again flood as before, if the levees were not built up higher from time to time. The flood-plain, however, no longer receives deposit. Therefore the river-bed being raised by deposit, and the levees by man, the river finally runs on the top of an embankment, which rises ever higher above the sur-

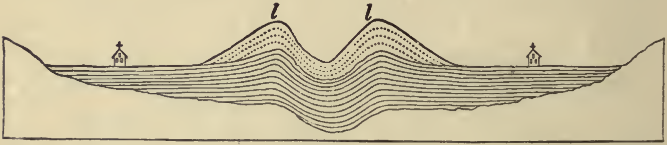

FIG. 12.—Ideal section of a river-bed and plain which was built up naturally for a time and then restrained by artificial levees, *l*, *l*.

rounding plain, and the danger from accidental breakage of the levee is ever greater (Fig. 12). It is said that the river Po, from this cause, *now* runs above the tops of the houses on the plain.

4. *Deltas.*

The flood-plain of a river may be divided into two parts, viz., the river-swamp and the delta. The river-swamp is that part of the flood-plain which was land-surface when the river began to run, and has been raised only a little by deposit. The delta is that part of the flood-plain which has been *reclaimed by the river from the empire of the sea.* The river has dumped sediment into the sea or lake, until it filled it up and made a certain amount of land. This made land is the delta. For example, Upper Egypt is the river-swamp; Lower Egypt, from Cairo seaward, is the Delta. The flood-plain of the Mississippi, from the mouth of the Ohio to about Baton Rouge, is river-swamp; thence to the Gulf it is delta.

A delta may be otherwise defined as an area of flat land at the mouth of rivers, usually of more or less triangular shape, over which the river runs by inverse ramification, emptying by many mouths. The point where the river commences to divide is the head of the delta. The area of some deltas is very great. The delta of the Nile is 10,000 square miles, the delta of the Mississippi is 14,000 square miles, and the common delta of the Ganges and the Brahmapootra is 20,000 square miles. The form of the Mississippi delta is very irregular. It runs out into the Gulf as a narrow tongue fifty miles long, and separated from the Gulf only by low, narrow embankments, which are continuations of the natural levees (Fig. 13).

Deltas are not formed by all rivers, but only by those which empty into tideless, or nearly tideless, waters. Streams running into pools, ponds, lakes, and rivers running into landlocked seas, make deltas; but rivers emptying into strongly tidal seas have wide, bay-like mouths or estuaries. The strong tides and waves not only carry away the sediment brought down and prevent land-making, but cut away and enlarge the mouths of the rivers. Thus, in this country, all the rivers emptying into the Great Lakes or into the Gulf of Mexico (where the tides are very small) make deltas, while all emptying into the Atlantic or Pacific have estuaries. So, in Europe, all the rivers emptying into the Mediterranean Sea, the Black Sea, the Caspian Sea, the North Sea, and the Baltic Sea, form deltas, while those emptying into the Atlantic have estuaries. The Ganges (Fig. 14) seems to be an exception to this rule; for it makes a great delta, although the tides in the Bay of Bengal are strong. The cause of this is the prodigious quantity of mud brought to the sea by the Ganges. Two opposite agencies are at work at the

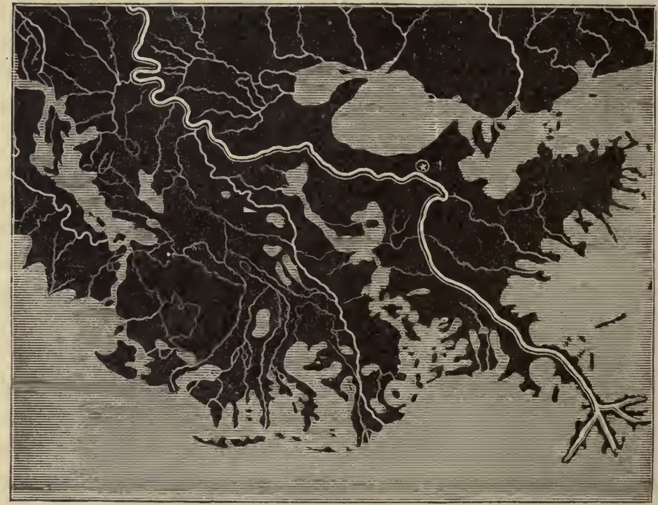

FIG. 13.—Mississippi delta.

mouths of rivers, viz., the river bringing sediment and making land, and the sea carrying it away and destroying land. If the former prevails, a delta is formed; if the latter, an estuary.

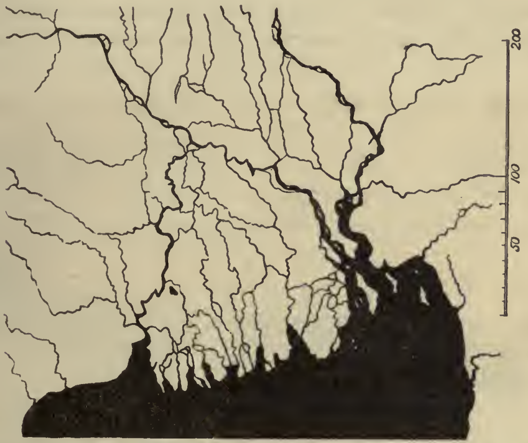

Fig. 14.—Delta of Ganges and Brahmapootra. (From De la Beche.)

Mode of Formation.—We are apt to imagine that we can not observe these phenomena except by becoming travelers. On the contrary, we may observe them in every little stream emptying into a pond. In every such case we shall observe a sand-flat over which the stream runs in many *rills,* that often change their position. Such a sand-flat is a delta. If we watch the process, we shall see that the stream before entering the pond carries sediment, perhaps is muddy. As soon as it strikes the still water, it spreads out in all directions, the velocity is checked, the sediment falls, the bottom is built up to the surface, and the delta commences. The sand or mud is now carried over the delta, and dumped beyond. Thus the delta grows from day to day (Fig. 15, *a*). The stream, as it runs over the sand-flat, is often choked with its own deposit, and compelled to seek new channels by dividing.

In the figure we have represented the case of a torrent, carrying coarse sediment, rushing down a steep slope into a lake or pond. In such a case the sediment falls quickly, the strata will be irregular and highly inclined; but, in the case of great rivers carrying sediments for long distances, the coarse material is all dropped higher up, and that which reaches the sea is very fine, and therefore sinks slowly. Hence in great deltas the stratification is nearly horizontal.

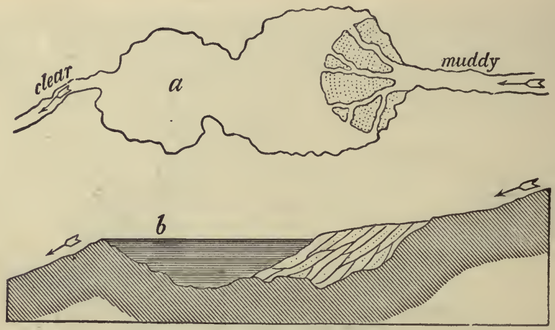

FIG. 15.—Ideal map (*a*) and section (*b*), showing the formation of a delta.

Again, the figure plainly shows that, if this process goes on, the lake or pond will be entirely filled. All mountain-lakes are being rapidly filled in this way, and a little close observation is sufficient to show that all high mountain-regions, like the Sierra or Colorado mountains, are full of marshes and meadows which are extinct lakes.

Age of Deltas.—All deltas are growing. The rate of growth in some cases has been observed. The delta of the Po has advanced twenty miles into the Adriatic Sea since Roman times, for the town of Adria, then a seaport, is now twenty miles inland. The delta of the Rhône has grown thirteen miles in the Christian era. The Mississippi delta is pushing seaward more rapidly than any other, evidently because it pushes along narrow lines. It is advancing now at the rate of three hundred and thirty feet per annum, or a mile in sixteen years, or six miles per century. The age of deltas can not, however, be got in this way, because the river often changes its mouth, and dumps its freight now here, now there, along the whole water-front of its delta. The *age* or *time* is usually estimated by getting the cubic *volume* of the delta, and dividing this by the annual *mud-discharge* $\left(T = \frac{v}{m.\text{-}d.}\right)$. But without more accurate observations than have yet been undertaken, these estimates are not entitled to much confidence.

5. *Estuaries.*

The wide mouths of certain rivers are called estuaries. We have already explained why some rivers have estuaries and some make deltas. All the rivers running into the Atlantic and Pacific Oceans have estuaries, because the tidal currents are stronger in carrying away than the river in bringing down and depositing sediments. The Bay of Fundy, the Hudson River to near Albany, the Delaware and Chesapeake Bays, Albemarle and Pamlico Sounds, the Bay of San Francisco, and the Lower Columbia River are estuaries. So also are the wide mouths of the Amazon and La Plata Rivers. So also the *firths* of Scotland and the *fiords* of Norway. The velocity and therefore erosive power of tides in estuaries is sometimes enormous. The trumpet-shaped mouth of the river takes in a large mass of the tide-wave. As this passes up it is compressed into a narrower channel, and therefore rises higher and rushes with increasing velocity. In the upper part of Bristol Channel the tide rises forty feet; in the Bay of Fundy, sixty feet; in Puget Sound, twenty feet. If the water be shallow and the resistance to advance great, the tide rises into a breaker, which advances at a rate sometimes twenty miles an hour. It is evident that the erosive or land-destroying power of such currents is enormous. Whatever is thus gathered in its upward course, together with whatever is brought down as sediment by the river, is all carried by the ebb-tide out to sea, and therefore lost to the land. In fact, of all places along the water-front, the mouths of rivers are the most vulnerable to the attacks of the sea.*

Deposits at the Mouths of Rivers.—The retreating tide carries away to the sea both what is gathered by the advancing tide and what is brought down by the river. Therefore the estuary is scoured out, rather than receives deposit. Yet, in certain sheltered coves—such as represented in Fig. 17, at *a* and *b*—stratified deposits will often be found. These are peculiar. They consist of an alternation of fresh-water, brackish-water, and salt-water deposits, known each by the shells which they contain. The reason is this: In dry seasons these coves are occupied by salt water only, and in flood seasons by fresh water only.

Also along the water-front of deltas some parts will be receiving sediments from the river, while other parts, receiving no such sediments, will be inhabited by marine animals. With the shifting of the mouth of the river, these latter may be again covered with river sediments. Therefore, in all deposits made at the mouths of rivers there will be an alternation of fresh- and salt-water deposits. And, conversely, *stratified deposits, consisting of such alternations, wherever found, are judged by geologists to have been formed at the mouths of ancient rivers.*

6. *Bars.*

The formation of bars is an admirable illustration of the laws of sediment-laden currents. Bars are formed at the mouths of all rivers by the fan-like spreading of the currents and the consequent checking of the velocity by contact with still water of the sea or lake. They are usually of semicircular or horseshoe-like form, as shown in Figs. 16, 17. In rivers forming deltas (Fig. 16) this is the only bar; but in rivers forming estuaries (Fig. 17) there are two bars—one at the mouth of the estuary, and the other at its head. The bar at the mouth is formed in the usual way, by the spreading of the current of the outgoing tide, the consequent checking of its velocity, and deposit of its sediment. It has, therefore, the usual semicircular or horseshoe form. There are usually passes or deeper channels through which the tides ebb and flow.

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* Estuaries are also often formed by subsidence of the land. They are then the drowned lower courses of rivers.

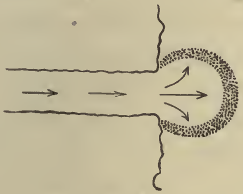
Fig. 16.

The bar at the head of the estuary or bay is formed by the meeting of two opposing sediment-laden currents, viz., the up-flowing tide and the down-flowing river. The meeting of these at every tide makes still water at that place, and the sediments from both are dropped there. In fact, at the head of the estuary there are three associated phenomena, all produced by the meeting of these opposing currents: 1.

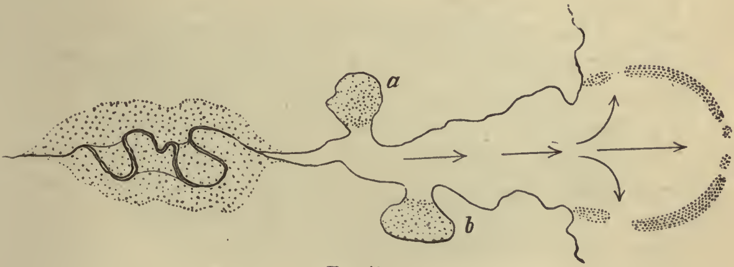

Fig. 17.

The backing up of the river-water by the tides causes it to overflow. There is, therefore, here a more or less extensive marshy or swampy flood-plain. 2. The river here not only forms a *bar,* but also a more or less extensive *flood-plain deposit.* 3. The river winds tortuously and in many channels through the soft, marshy soil, forming many marshy isles. These facts are shown in Fig. 17. In fact, we have here many of the phenomena of a river-delta. The Hudson River, for example, is an estuary, one hundred and twenty miles long. The tide runs up and meets the river-current, and makes still water about twenty miles below Albany. At this point is the bar. At this point also is an extensive marshy overflow-land, through which the river winds its tortuous course. The same phenomena are seen at the head of the Bay of San Francisco. The river here winds, by many tortuous channels with islands between, through an extensive marsh (*tule*-lands). The bar is also, of course, found here.

Removal of Bars.—If a bar be scraped away, it will be re-formed by the same agencies which originally formed it. Only constant dredging can improve it. If the river-channel be contracted by dikes so as to increase the velocity of the current, it will indeed scour out the bar, but the latter will again form at a new point of equilibrium a little lower down. In rivers forming deltas the bar has been successfully removed, in some cases, by means of jetties extending beyond the mouth of the river into the sea or gulf. The now swifter current scours out the bar, and the sediment is delivered in deep water, where it must deposit a long time before the bar is re-formed. The most remarkable examples of such improvement of bars are at the mouth of the Danube by the Austrian Government and at the mouth of the Mississippi by the United States Government.

We have now traced the agency of rain and rivers from mountains to sea. In fact, in the phenomena of estuaries and bars, we have already a coöperation of rivers and sea. This brings us very naturally to the next head, viz., *Agency of the Ocean.*

SECTION II.—THE OCEAN.

Waves and Tides.

The ceaseless beating of *waves* on an exposed shore can not fail to impress the observer as a powerful erosive agent. *Tides* assist the waves, not only by creating powerful currents in all bays, inlets, and estuaries, as already explained, but also by lifting the sea-level and therefore presenting new points of attack. As in the case of rivers the erosive power is greatly increased by the sand, gravel, and pebbles carried by the current, so in the case of waves the sand, gravel, shingle, and rock-fragments torn from the cliffs are taken up again and hurled back with violence, and become the chief agents of further erosion. Although, however, so incessant and violent in action and so conspicuous in effects, yet, being confined wholly to the shore-line, the aggregate effect of wave-erosion is far less than that of the universal erosion of rain and rivers.

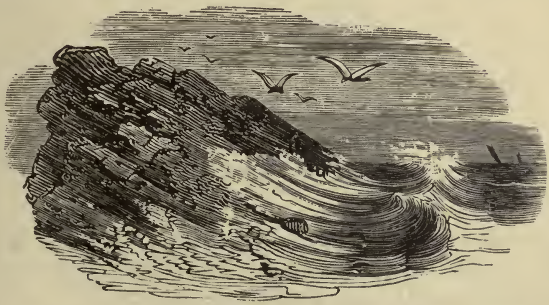

FIG. 18.—View of inclined strata, with faces exposed to waves.

Resulting Forms.—It is interesting to trace the forms of coast-lines to their causes. If the country-rock be stratified, and the strata dip toward the sea so as to present their faces to the waves, then the erosion will be *slower* and the coast-line comparatively *even* (Figs. 18, 20, *a*). If, on the contrary, the strata be level and the waves act on the edges (Fig. 19), then the cliff will be undermined, overhanging tables will fall from time to time, and the erosion will be rapid. Finally, if the edges of vertical or inclined strata be turned toward the waves (Fig. 20, *b*), then the coast-line will be deeply dissected, i. e., composed of alternate headlands and inlets. In these inlets, the waves, gathering force as they are pressed into narrower channels, beat with prodigious force.

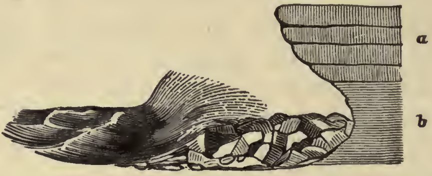

Fig. 19.—Section view of level strata, *a* and *b*, with edges to waves.

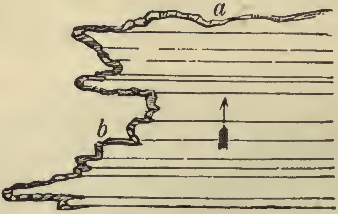

Fig. 20—Map view of inclined strata, dipping northward, as shown by arrow. *a*, faces to waves; *b*, edges to sea.

Again: since waves and tides act only on the shore-line as high as they can reach on the one hand, and as deep as they can touch bottom and form breakers on the other, it is evident that they act as a horizontal saw, cutting down the land a little below the sea-level. Hence, along a shore-line which has suffered much from beating waves, we are apt to find first a steep, perhaps overhanging cliff; then a level, submarine plateau; and then, as we go farther, a sudden falling off to deep water. In Fig. 21, the dotted line shows the original configuration of land and position of the shore-line. Such level plateaus, terminated by cliffs, are often found far inland. In some cases, though not in all, *they indicate old sea-cliffs.*

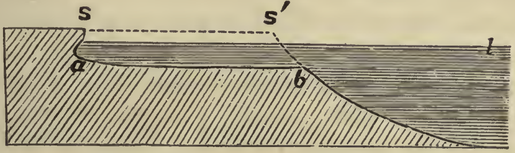

Fig. 21.—Ideal section view of submarine plateau and shore-cliff: *l*, sea-level; *a*, *b*, submarine plateau; *s*, present, and *s′*, the original, shore-line.

Nearly all shore-lines are receding under the incessant action of waves and tides, but the rate is very different in different places. As rain-erosion is concentrated on certain lines, giving rise to surface inequalities, such as gorges, ravines, cañons, etc., so wave and tide erosion give rise to nearly all the inequalities of coast-line. The general form of continents, and their largest inequalities, are doubtless due to other (i. e., continent-making and mountain-making) causes; but all the promontories, harbors, bays, etc., are due to ocean-erosion. As land scenery is due mainly to rain and river erosion, so sea-shore scenery is due mainly to sea-erosion. Every projecting promontory will usually be found to consist of hard rock, and every indentation is determined either by the softness of the rock or else by the mouth of a river giving entrance to powerful tidal currents.

Examples are found on every coast. In our own country the rocky shores of New England everywhere show the wasting action of waves. Farther south the coast is wasting in some places and gaining in others ; for, as we shall see hereafter, waves and tides may *make* as well as destroy land.

In Europe examples are more numerous and striking, and have been more carefully studied. The rushing tide through the English Channel and Dover Strait has greatly enlarged and is still enlarging the channel. The eastern coast of England is now being eaten away at the rate of from three to five feet per annum. The church of the Reculvers, which stands near the mouth of the Thames, and for many centuries has been a landmark for ships entering that port, stood, in the time of Henry VIII, one and a half miles inland, on a high cliff. It is now on the sea-margin, and would have long ago fallen into the sea if it had not been saved by an artificial sea-wall. Many isles in the German Ocean have entirely disappeared in this way. Heligoland is fast going, and already almost gone.

The western coast of England, Ireland, and Scotland is wasting less rapidly at present, but only because nothing but hard rock is left. The deeply dissected coast-

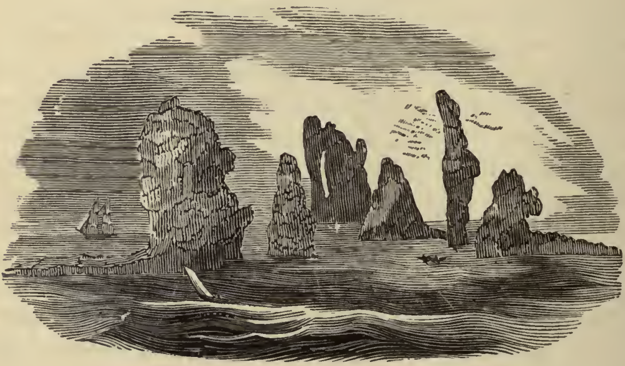

FIG. 22.

lines, with high promontories, separated by deep inlets, show the waste they have suffered in previous geological times. As we go north, the evidences of destruction become more and more conspicuous. To the north of Scotland, among the Hebrides, Orkneys, and Faroe Islands, are found groups of bare, wave-worn rocks, standing in the midst of the sea, mere skeletons of once fertile islands (Fig. 22).

But all these effects, viz., boldness of the headlands, the depth of the inlets, the intricacy of coast-dissection, reach their highest point on the coast of Norway. Any good map of this country (see Fig. 23) shows that the whole coast consists of alternate promontories and inlets. The promontories are rocky headlands, 2,000 to 3,000 feet high, and the inlets run 50 to 100 miles inland. Such deep inlets, separating high headlands, are called *fiords*. Closer inspection shows a line of islands off the coast. These are rocky islands 2,000 to 3,000 feet high, and of hardest granite. These granite isles are probably the *axis* of the Scandinavian mountains—in fact, of the Scandinavian Peninsula. If so, then it would seem that the whole western slope of these mountains has been swept away, that the sea has already broken through the axis or backbone, and is now gnawing among the ribs on the eastern flank. On nearly all bold and severely beaten coasts we find such off-shore islands, which are the fragments of a former coast-line.

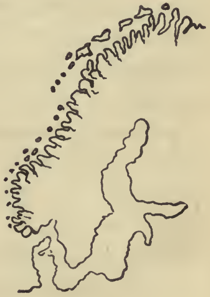

FIG. 23.—Map of Norway coast, showing the dissected coast-line and islands off shore.

The present form of the Norway coast, however, is not wholly due to sea-erosion, but also largely, as we shall show hereafter, to subsidence. Yet, as Norway is perhaps the oldest part of the European continent, we have probably not exaggerated, in what is said above, the ravages it has suffered from its ancient enemy, the sea.

Transportation and Deposit.—The lifting power of waves is immense, often taking up rock-fragments of many tons weight and hurling them with violence against the shore-line; but they usually carry only a very short distance. Under certain conditions, however, waves may transport materials for many hundreds of miles. Thus, on account of the trend of the Atlantic coast and the prevalence of north winds, the coast material is cast up on shore and falls off a little southward with every wave. Thus, shore-sands creep southward slowly, even to the point of Florida, although the coast-rock of Florida is all limestone. So, also, the shore-sands of Lake Michigan are carried southward by wave-action, and accumulate about Chicago.

Though waves are usually *de*structive rather than *con*structive, yet they often add to the land along shore-lines by *deposits*. Such deposits are very characteristic: 1. They are usually coarse material and thoroughly water-worn—i. e., *round-grained* sand, gravel, or shingle. 2. The lamination is often highly inclined and irregular. 3. They are often affected with ripple-marks (Fig. 24).

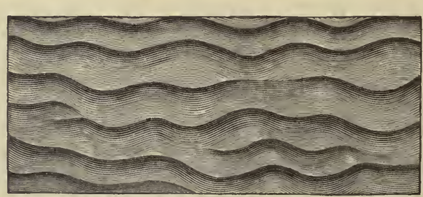

FIG. 24.—Ripple-marks.

4. They are often impressed with tracks of animals and with rain-drops. Now, all these marks are found in rocks far inland and high up the slopes of mountains. We can thus

often recognize the old shore-lines of previous geological epochs.

Oceanic Currents.

The earth is covered with two oceans, an atmospheric and an aqueous. The former covers the whole of it, fifty or more miles deep; the latter covers three quarters of it, three miles deep. On the surface of the one we swim and sail, on the bottom of the other we crawl. Both of these oceans are in constant circulation in every part. The currents in the one are winds, in the other oceanic streams. The *cause* of circulation and the general *directions* of the currents are also the same. There is, indeed, some difference of opinion as to the *immediate* cause of oceanic currents; but there can be no doubt that, *directly* or *indirectly,* they, like winds, are caused by difference of temperature between the equator and the poles. In both cases, too, there are disturbing causes which complicate the result. In the one case, local variations of temperature and extreme mobility of the medium; in the other, the existence of unseen submarine banks, and especially of impassable barriers, the continents. As our sole object is to discuss their geological agency, we shall describe but one of these great oceanic currents as an example.

Gulf Stream.—This stream takes its origin in the equatorial current which, stretching across the Atlantic from the coast of Africa, strikes the wedge-shaped eastern point of South America and divides north and south. The larger northern branch runs along the coast of South America into the Caribbean, and thence through the Straits of Florida into the North Atlantic. After passing the point of Florida it turns north, runs along the coast of the United States, turns eastward from the coast of Labrador, and, after sending a branch toward the Arctic region north of Europe, turns southward to join again the equatorial current on the coast of Africa. The amount of water carried by this ocean-stream is probably greater than that of all the rivers in the world. It is equivalent to a stream fifty miles wide, one thousand feet deep, and running at a rate of three miles per hour. Its extreme velocity, where it passes through the Straits of Florida, is four to five miles per hour.

Geological Agency.—Oceanic streams run on beds and between banks of *still water,* and therefore, probably, have no erosive agency, but they are important agents in the transportation and distribution of sediments. All the *débris* of land-surfaces are brought by rivers to the water-front and dumped there. Tides, in their retreat, may take these seaward a few miles, but these also soon lose their velocity and drop their freight. Were it not for oceanic currents, therefore, the whole *débris* of land-surfaces would be dropped within thirty to fifty miles of the shore-line. As it is, nine tenths are so dropped. *Marginal sea-bottoms are, therefore, the great theaters of sedimentation.* Nevertheless, a small portion of finest sediment is carried within reach of oceanic currents, and by them strewed broadcast over portions of deep-sea bottom.

We find good examples of this in the course of the Gulf Stream. The sediments of the Amazon may be traced from its mouth seaward for a great distance. It is then taken by oceanic currents and carried northward, and much of it deposited on the coast of Guiana, three hundred miles distant, and the remainder into the Caribbean Sea. According to Humboldt, much sediment is carried from the Caribbean into the Gulf of Mexico. The stream receives there also, possibly, contributions from all the Gulf rivers, especially the Mississippi, and may deposit these again along the coast of Florida and the Bahama Islands.

The surface transparency often conspicuous in oceanic currents is no evidence against their carrying sediments; for there is this difference between rivers and oceanic streams: In rivers, besides the general current, there are partial currents, from side to side and up and down, which keep the stream turbid to the surface; while ocean-streams, running on beds and between banks of still water, have no such partial currents. There is nothing to prevent sediments settling exactly as in still water. Thus ocean-currents usually carry sediments, if at all, only in their deeper parts. Deep-sea deposits are undoubtedly of great importance, but only recently have attracted much attention.

Submarine Banks.—These are formed by checking the velocity of sediment-laden currents, whether tidal or oceanic. The checking may be caused by the meeting of two opposing currents, or by the current passing through a narrow strait into a wide sea. In other words, submarine banks are formed under the same conditions as bars;

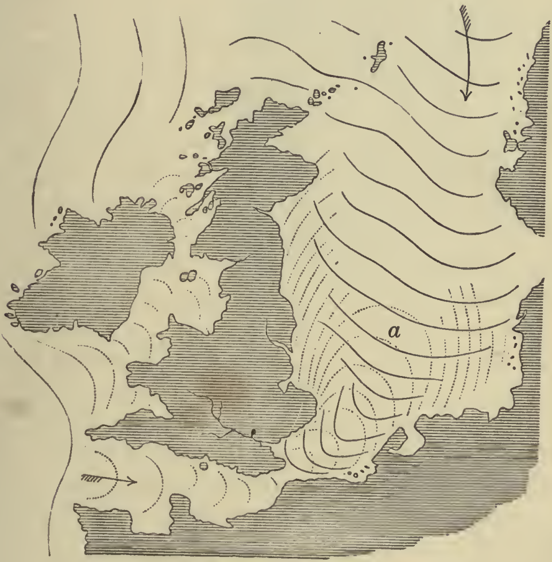

Fig. 25.—Tides of the German Ocean.

and bars at the mouths of rivers are, in fact, one form of submarine bank.

The best examples of banks formed by *tidal currents* are found in the North Sea. It is seen in the map, Fig. 25, that the tidal wave from the Atlantic, striking on the British Isles, divides into two parts, one entering the North Sea through Dover Strait, the other by the Shetland and Faroe Islands. That through Dover Strait runs swiftly through the narrowing channel, gathering much sediment. As soon as it passes Dover Strait it spreads fanlike, its velocity is checked, and it deposits sediment. In the mean time the other branch, coming in from the north, meets the southern branch, and makes still water at some point, as *a*, and deposits sediment. Again, all the rivers emptying into this sea from the south form bars at their mouths. To these several causes are due the numerous banks which render the navigation of this shallow sea so dangerous. Banks are formed also by oceanic currents. For example, the Gulf Stream, passing through the Straits of Florida, eddies on both sides and forms the Bahama and Florida Banks. Again, the Banks of Newfoundland are at least partly formed by the Arctic current bearing icebergs loaded with *débris* from Greenland (see pp. 66, 67), meeting the warm Gulf Stream, whereby the bergs are melted and their burden dropped.

Land formed by the Agency of Waves.—We have spoken of waves only as *destroying* land, but under suitable conditions they also *form* land. On submarine banks, however produced, islands are formed by waves. When by sedimentary deposit the bank is built up to near the water-surface, so that the waves *touch bottom* and form breakers, then the bank is beaten up above the surface and forms islands, which continue to grow by the same agency. Such islands are always low, narrow, and long in the direction of the coast-line. In this way are formed the small islands which overdot the surface of extensive submarine banks—also the low islands about the mouths of estuaries and harbors, such as Sandy Hook and Coney Island about New York Harbor, and the long sand-spits off the shores of shallow seas, as, for example, the shores of North Carolina (Fig. 26), and nearly the whole southern Atlantic coast. The *débris* brought down by the rivers to the estuaries is carried by the retreating tide seaward and dropped near shore. On the sea-margin bank thus formed, the waves beat up long, narrow sand-spits, separated only by tidal inlets. This is the condition on the North Carolina coast. These barriers to the retreating tide then cause the estuaries to fill up, until they are separated from the mainland only by narrow tidal channels. Thus are probably formed the sea-islands on the South Carolina coast. Finally, the tidal channels may be filled up, the islands added to the land, and the coast-line transferred seaward.

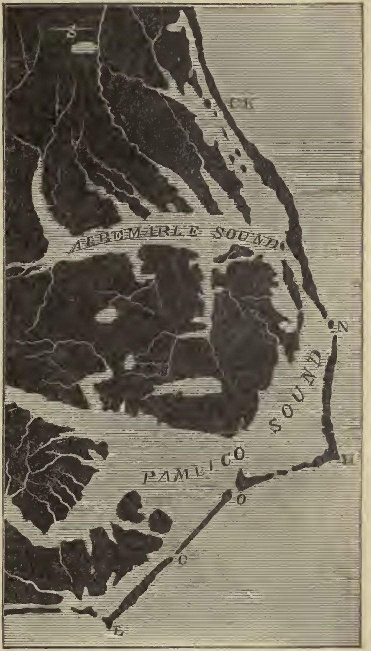

Fig. 26.—North Carolina coast.

Along nearly all coasts we find a line of small islands. These are of two kinds. The one consists of high, rocky islands, off bold coasts, as in Norway, Greenland, etc.; the other of low, sandy islands, off level coasts, as on the southeastern coast of the United States. Those of one kind are formed by land-destroying, of the other kind by land-forming action of waves. The one are the scattered *remnants* of an *old* coast-line, the other the *beginnings* of a *new* coast-line.

SECTION III.—ICE.

Ice may act either as land-ice—*glaciers,* or as floating ice—*icebergs.*

Glaciers.

The action of glaciers can not be observed by every one in his own locality, since they exist only in very high mountains or in high latitudes; but the subject is a very fascinating one, and some knowledge of it gives additional interest to mountain-travel.

The summits of high mountains, especially in cool, moist climates, are not only covered with perpetual snow, but from this snow-cap there extend down the valleys, far below the region of perpetual snow, solid masses of ice, which are in continual, slow motion downward. These *valley prolongations of the snow-caps*—these *moving masses of ice,* these *ice-streams*—are called *glaciers.*

All mountain-peaks and mountain-ridges are trenched on the sides with radiating or transverse valleys. Now, if we imagine such a peak or ridge to be covered deeply with snow and ice, and if we imagine, further, that ice is a stiffly viscous substance like pitch, so that under the heavy pressure of the thick mass it runs slowly down the slope of the valleys to half-way down the mountain, then we have the condition of things as they exist in the Alps, or in any other glaciated region. In most mountains the valleys are occupied by rivers; in glacial regions they are occupied in their upper parts by glaciers, and in their lower parts by rivers. As rivers, so glaciers, have their tributaries, only the tributaries of glaciers are far less numerous than those of rivers.

We have said that glaciers are in continual, slow motion down the valley; yet in temperate climates they do not reach the sea—they do not reach beyond a certain point, called the *lower limit of glaciers.* Under constant conditions the snout of the glacier remains unmoved at this place, even though the glacier is in constant current-motion. This apparent anomaly may be explained thus: The glacier may be regarded as under the influence of two opposite forces. Gravity urges it by slow motion downward, and, if this acted alone, the glacier would run into the sea. But the ice is constantly melted, more and more, as the glacier presses downward into warmer regions; if this alone acted, the point of the glacier would retreat to the summit-snow. Now, where these two forces—one tending to lengthen, the other to shorten the glacier—balance each other, is found the lower limit of the glacier where the snout rests unmoved. Sometimes, after a succession of cool, moist years, or a succession of heavy snowfall years, the melting is less rapid or the motion more rapid, and the snout of the glacier will slowly advance, perhaps invading cultivated fields and overturning houses. Sometimes, on the contrary, from more rapid melting or less rapid motion, the snout will recede, strewing *débris* in its former bed. But, whether the snout stands *still*, or moves *forward*, or moves *backward*, the matter of the glacier is moving constantly downward. In this respect, glaciers are like rivers in certain dry regions. These rivers rise in the mountains, run a certain distance, but never reach the sea—never pass a certain point where the supply is balanced by waste from evaporation.

We have said that glaciers reach far below the line of perpetual snow. In the Alps, for example, the lower limit of glaciers is 5,000 feet below the snow-line. This

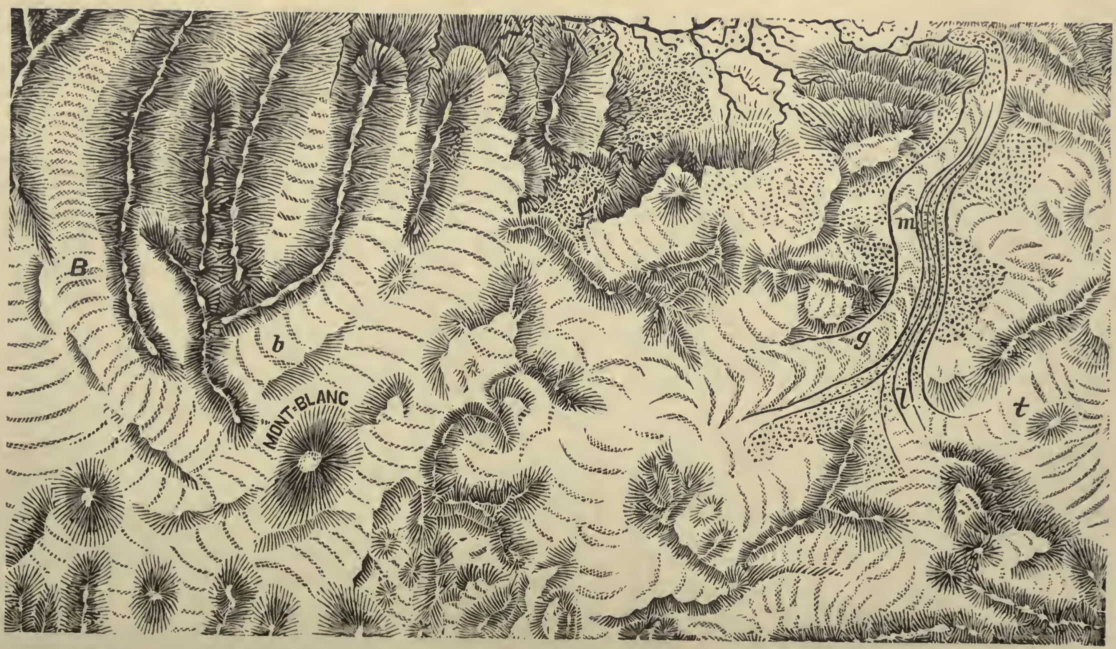
B
b
MONT-BLANC
m
g
l
t

FIG. 27.—Mont Blanc glacier region. *m*, Mer de Glace ; *g*, Du Géant ; *l*, Léchaud ; *t*, Talèfre ; *B*, Bionassay ; *b*, Bosson.

shows that the mass of ice is so great that, although moving at a rate of only a few feet a day, it may reach a mile

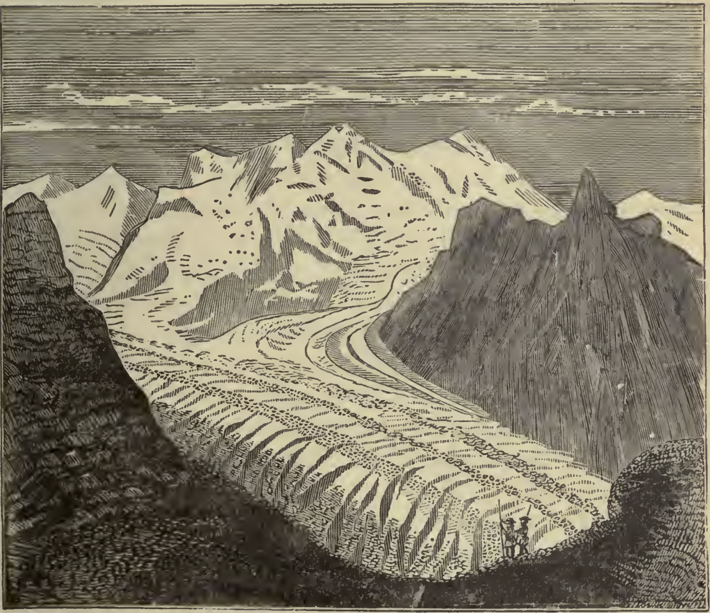

Fig. 28.—Zermatt glacier. (After Agassiz.)

below, and many miles beyond, the snow-line before it is all melted. In high latitudes, where the snow-line comes nearer the sea-level, glaciers not only touch the sea, but run far into the sea, and, breaking off, form icebergs.

General Description of a Glacier.—In glacial regions, where the summit snow-fields are large, every valley is filled for a certain distance with a glacier. In the Alps the glaciers are five to fifteen miles long, one to three wide, and two hundred to six hundred feet thick. In the Himalayas they are twenty to forty miles long. In the United States (exclusive of Alaska) the largest glaciers occur in Washington. White River glacier, on Mount

Rainier, Washington, is ten miles long and five miles wide. On Mount Shasta, California, glaciers are found five miles long. In the Sierra, California, and in the Wind River Mountains, Northwestern Wyoming, small, imperfect glaciers still linger in the highest and shadiest valleys, near the summits. Many glaciers are also found in Norway, and especially in Alaska. But it is only in polar regions that glaciers are developed now in such proportions as to give us any adequate idea of their great importance as a geological agent. Greenland is a land-mass of almost continental size, being 1,200 miles long and 600 wide. It is apparently completely covered with snow and ice, to a depth of 2,000 to 3,000 feet. This whole ice-mantle moves bodily seaward, and divides only at the coast into separate glaciers, running into the sea through fiords, and there forming icebergs. These separate marginal glaciers are a mere fringe to the great interior ice-sheet, and yet many of them are thirty to forty miles long and many miles wide.

General Structure.—As we go from the summit down a glacial valley, we pass from ordinary snow through granular ice (*névé*) to the perfect ice of the glacier proper. This glacier-ice, however, is not clear, solid ice, but *mainly* a white vesicular ice, though traversed in many ? places by veins of clear, blue, solid ice, which gives the whole a striped or agate-like appearance. Moreover, the glacier is broken by great transverse fissures, which often reach clear to the bottom (*crevasses*), by many marginal fissures along the sides, and by smaller, even capillary ? fissures, which give it a more or less grained structure.

As the ice is constantly melting by the heat of the sun and air and by contact with the rocky bed, the surface is full of streams. These soon fall into crevasses, and find their way to the bottom and down the glacier-bed to the valley below. Thus from the snout of every glacier runs a stream. The surface of a glacier is not smooth, as might at first be supposed, but usually very rough. This roughness is due partly to rock-fragments from the crumbling cliffs on each side, as will be presently explained; partly to the unequal melting of the ice by the sun, producing pinnacles and hollows, as erosion produces hills and valleys on land; and partly to the crevasses. For these reasons, the travel over the surface is often not only difficult but dangerous, especially as the crevasses are often concealed by recently fallen snow.

Moraines; Lateral Moraines.—On each margin of a glacier, near the bounding cliffs, is found a continuous pile of *débris*, consisting of earth and rock-fragments of all sizes up to many hundred tons weight. The pile may be twenty to thirty feet high, and is itself raised on an ice-ridge formed by the protection of the ice beneath from the melting power of the sun. These two marginal piles of *débris* are called the *lateral moraines*. They are formed by the constant fall of rocks and earth from the crumbling cliffs on each side. But as the cliffs are not everywhere so steep that their fragments reach the glacier, if the glacier were motionless the contributions would be in isolated heaps only. But the motion of the glacier converts these separate contributions into a continuous ridge; and, conversely, the continuity of the moraines is a proof of the motion of the glacier.

Medial Moraine.—When two tributary glaciers unite to form a trunk-glacier, the two interior lateral moraines of the tributaries unite, and from the angle between the two tributaries will train off as a continuous ridge of *débris* along the middle of the trunk-glacier to its point. This is called a *medial moraine*. It is still more indisputable proof of the motion of the glacier, since it is obviously impossible for *débris* to reach the middle of a glacier in any other way. The number of these medial moraines will depend upon the complexity of the glacial system, for there will be one for every tributary (Fig. 29). Even a rocky island in the middle of a glacier or of a tributary will give rise to a separate train. Thus, complex glaciers, with many tributaries, may be covered with these trains.

Terminal Moraine.—Remembering that glaciers are in constant motion and yet never pass beyond a certain point, it is evident that everything which is carried by the glacier must find its resting-place at the foot. Here, then, we find an enormous, irregularly concentric pile of *débris*, the accumulation of ages. This is called the *terminal moraine*. It is composed mainly of materials carried on the surface of the glacier (top moraine), but also to some extent of materials pushed out from beneath (ground moraine).

The Motion of Glaciers and its Laws.—That glaciers are actually in continual motion downward is proved by the constant change of position, in relation to points on the bounding cliffs, of conspicuous bowlders lying on the surface of the glacier. From day to day and from year to year these are carried farther and farther down the valley. With a good theodolite the movement of objects on the surface may be observed from hour to hour. Thus, not only the fact and the rate but the laws of motion have been determined. The rate of motion of Alpine glaciers is one to three feet per day. The average rate of the Mer de Glace (Fig. 29) is estimated by Forbes as about five hundred feet per annum. The extreme length of the glacier is ten miles. A stone fallen upon its upper part would find its resting-place on the terminal moraine only at the end of one hundred years. Everything upon or beneath or within the substance of the glacier is finally deposited there. A striking and sad illustration of this is found in the fact that, in several cases, the mangled remains of adventurous climbers, who have fallen into crevasses and perished, have appeared, after many years, at the foot of the glacier.

Laws of Motion.—A glacier moves, not like a *solid* body, all together, sliding on its bed, but exactly like a *stiffly viscous* body. In other words, the motion of a glacier is a *current-motion*. Like a river, it not only slides on its bed, but also the different parts move with

sticky

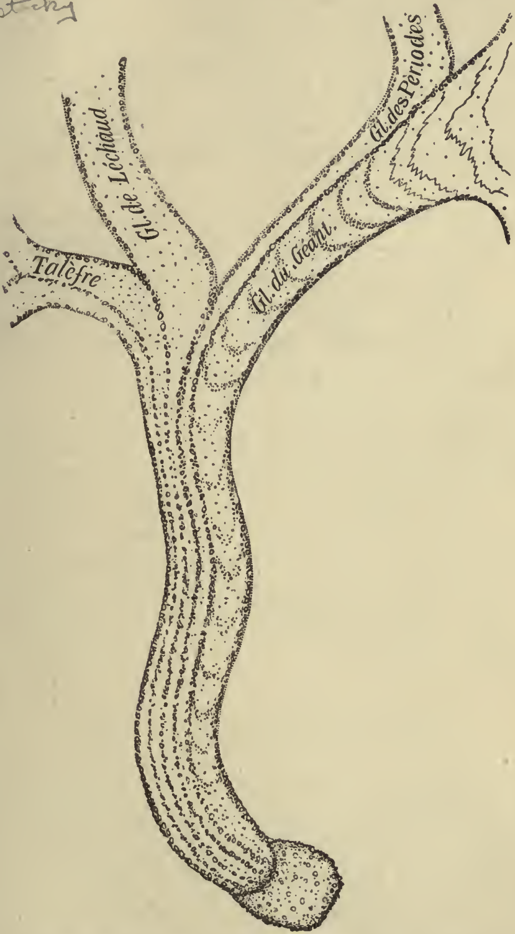
Gl. de Léchaud
Talèfre
Gl. des Periodes
Gl. du Geant

FIG. 29.—Mer de Glace, with its tributaries and its moraines.

different velocities, and therefore slide on each other. This is called *differential* motion, and is characteristic of fluid, as distinguished from solid motion. But the differential motion of glaciers is not free, like that of water, but reluctant, and with much resistance, like that of very *stiff pitch.* In small masses, and under quickly applied force, it breaks like a solid ; but in large masses, and under heavy, slowly applied force, it behaves like a stiffly viscous fluid.

Thus, like rivers, glaciers move much faster in the middle than on the margins, and on the top than near the bottom. Like rivers, also, they move faster on steep than on gentle slopes. Like rivers, also, the velocity increases with the depth of the stream. For example, the Mer de Glace is 350 feet deep, and moves a foot and a half per day, while some of the great Greenland glaciers, 2,000 to 3,000 feet deep, with less slope, run sixty feet per day. Like rivers, also, glaciers conform to the inequalities of their bed and banks, but, as it were, reluctantly—i. e., they conform to large and gentle inequalities, but not to the small and sharp ones. In a word, glaciers, like rivers, have their narrows and their lakes, their shallows and their deeps, their cascades and their level reaches. They are truly *ice-rivers.*

Glaciers as a Geological Agent.

The structure, the properties, and the cause of the motion of glaciers are questions of deepest interest to the physicist, but it is their *geological agency*—i. e., their agency now, and still more in former times, in sculpturing the earth's surface—which chiefly concerns the geologist.

We have seen that a glacier may be regarded as an ice-river. Like rivers, therefore, glaciers *erode* their beds and banks, *transport* materials, and make *deposits.* But in all these respects the effect of their action is very characteristic, and can not be mistaken for that of water.

Erosion.—When we remember the thickness and weight of glaciers, we at once see that they must rub with great force on their beds. But, like water, glaciers will do but little work without graving-tools. Rivers erode mainly by means of sand, gravel, and pebbles, carried along the bottom; glaciers, by means of rock-fragments of all sizes carried between the ice and the beds, and often *fixed* by freezing in the ice. These graving-tools are partly fragments broken off from the bed, and partly fragments fallen on the surface, which become ingulfed in crevasses or jammed between the sides of the glacier and the bounding cliffs. In either case, by virtue of the viscosity of the glacier-ice, they find their way finally to the bottom. By virtue of the hardness and stiffness of the ice, it tends to *plane* to one level; by its smoothness, it *polishes;* by means of its graving-tools, it *scores* in straight, parallel lines; by virtue of its viscosity, it *conforms* to the large and gentle *inequalities*, giving rise to smooth, billowy surfaces, called *roches moutonnées.* Thus smooth, billowy surfaces, scored with straight, parallel marks, are very characteristic of glacial action. We shall call such surfaces *glaciated* (Fig. 30).

Transportation.—The transporting power of running water increases as the sixth-power of the velocity. Even at this enormous rate of increase, blocks of stone of many hundreds of tons weight, such as are often found in the paths of glaciers, would require, if carried by water, an almost incredible velocity. But glaciers carry materials resting on their surfaces, and therefore of all sizes, with equal ease. Rock-fragments of thousands of tons weight are carried by them and left in their path by retreat.

Again, fragments carried by water are always more or less bruised, worn, and rounded, while fragments carried on the *surface* of glaciers are *angular*. Again, water-currents set down blocks of stone in *secure* positions; while glaciers, in their slow melting, often leave them

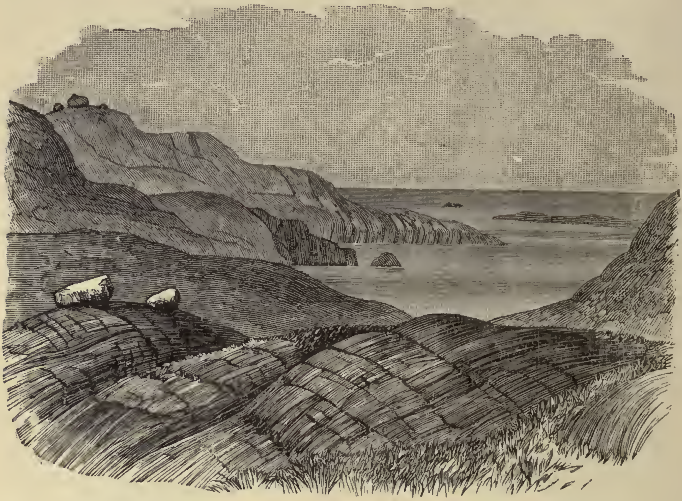

FIG. 30.—Glaciated surface with perched bowlders. (After Geikie.)

perched in *insecure* positions, and even sometimes as *rocking-stones.*

Deposit.—Materials deposited by water are always neatly sorted and stratified; the materials deposited by glaciers in terminal moraines are a confused heap of fragments of all sizes, from fine earth to great blocks of stone, dumped together *without sorting.* This heap consists of two parts: the one contributed from above, the other pushed out from below (*ground moraine*); the one consists of loose earth and *angular* fragments, the other of compact clay and *rounded, striated* fragments. Both are wholly unstratified.

Evidences of Former Extension of Glaciers.—The characteristic signs of glaciers, therefore, are smooth, scored, *moutonnéed* surfaces of rocks, large angular perched blocks, and confused piles of rubbish, forming terminal moraines. It is by evidence of this kind that it has been proved that at one time glaciers were far more extended than now in regions where they still exist, and existed in great power in regions where they are no longer found; in other words, that there was once a *glacial epoch.* In the Alps, for example, polished, scored, *moutonnéed* rocks and perched bowlders are found on the sides of the valleys far above the present level of the glacier (old glacial flood-marks), (Fig. 31); also, smoothed, scored, *moutonnéed* rock-beds and deserted terminal moraines are found far beyond the present foot of the glacier. They mark the former position of the foot. Behind these old terminal moraines, the waters flowing from the glaciers are dammed, and thus form lakes. Similar phenomena are observed in regions where glaciers no longer exist—as, for example, in the Sierra and Colorado mountains. As these phenomena belong to the glacial epoch, it is best to describe them in connection with that subject (p. 386).

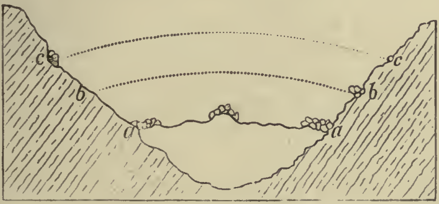

FIG. 31.—Ideal section of a glacier bed. *a*, *a*, present level; *b*, *b*, and *c*, *c*, former levels.

Pot-holes in Old Glacial Beds.—Pot-holes of enormous size like great stone wells, 10–15 ft. wide and 20–30 ft. deep, are often found in old glacial beds. They naturally excite the wonder of the inhabitants of Alpine regions and are called by them "*Marmites des Géants,*" or Mortars of the Giants. They are formed not by the ice but by the rushing waters of the subglacial streams, or else by the falling of superglacial streams through great fissures in the ice (crevasses) to the rocky bed below.

Icebergs.

We have already stated that in high-latitude regions the lower limits of glaciers touch the sea. In South America this occurs in 45° south latitude; in Norway, in 65° north latitude; and in Alaska, in 60° north latitude. Still nearer the poles they run far into the sea, and by the buoyant power of water, and the up-and-down movement of tides and waves, are broken off in great prismatic masses, and float away as icebergs. In the North Atlantic the great source of icebergs is Greenland; in the Southern Ocean, the Antarctic Continent.

Greenland.—We have already said that Greenland is completely covered with an ice-mantle 2,000 to 3,000 feet thick, which moves bodily, by slow glacial motion, seaward, producing doubtless universal erosion; and divides only at the margin into separate glaciers, which, running through great fiords, thirty to forty miles long, into the sea, there form icebergs. These are then taken by oceanic currents and carried southward into warmer waters, where they melt (Fig. 32).

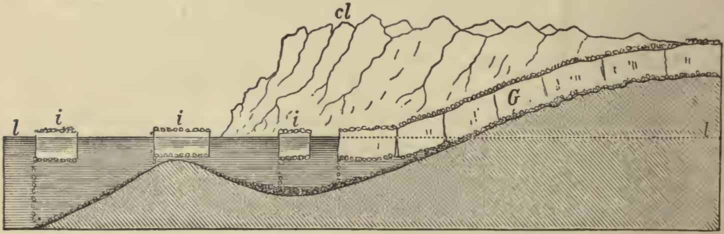

FIG. 32.—Ideal section of a fiord and glacier, forming icebergs. *l*, *l*, sea level; *G*, glacier; *i*, *i*, *i*, icebergs; *cl*, cliffs.

It is easy to see the necessity of this process. The amount of snow which falls in polar regions is far greater than the waste by melting and evaporation in the same regions. If there were no means of disposing of the excess, it would accumulate without limit. This is prevented, and the equilibrium restored by the running off of this excess into the sea as glaciers, and the breaking off as icebergs, which then float away to warmer latitudes, and, there melting, are returned into the general circulation of meteoric waters.

Description.—The coast of Greenland, like that of Norway, consists of bold, rocky headlands and deep fiords and high islands off shore. Into each fiord runs a glacier, and *from* each emerge numberless icebergs. Baffin's Bay is, therefore, full of icebergs of all sizes, from a few hundred feet to many thousand feet on a side. Sometimes several hundred may be seen at one view. They are often two hundred to three hundred feet high, and, since only one seventh is above water, some of them must be at least two thousand feet thick. In shape they are at first more or less prismatic (Fig. 32), but by the unequal melting of the sun and air, they become finally extremely

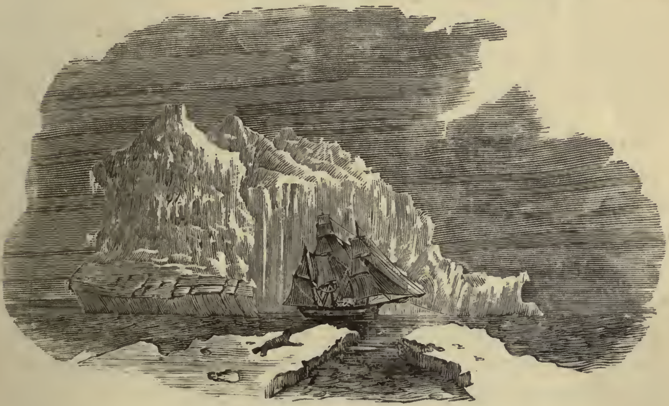

FIG. 33.

irregular, assuming often striking forms of mountains, castles, cathedrals, etc. (Fig. 33).

In Antarctic regions the development of ice is even greater. Whatever of land exists there, is completely covered with a universal ice-mantle, which pushes out ten miles to sea as a continuous *ice-barrier*. From the margin of this barrier break off regular prismatic blocks of enormous size and thickness (Fig. 34)

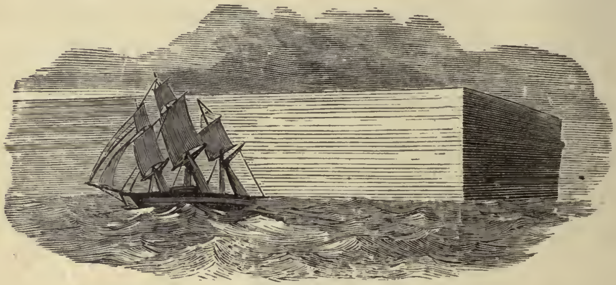

FIG. 34.

Icebergs as a Geological Agent.

Erosion.—Since icebergs are floating bodies, they do not erode unless they ground. In places like the Banks of Newfoundland, where icebergs ground in great numbers, they doubtless disturb the bottom. But, when we remember the irregularity of their movements, under the action of waves and tides, and also that the sea-bottom is deeply covered with ooze, we may safely assert that no smooth, striated, *moutonnéed* rocks, such as are produced by glaciers, would be found there.

Transportation and Deposit.—But, in the transportation and distribution of materials very widely over the sea-bottom, the agency of icebergs is very important. The Greenland ice-sheet, since it is universal, can carry *no moraines atop,* but it everywhere pushes seaward its *ground moraine.* In addition to this, as soon as it divides at the land-margin into separate glaciers which run down into the fiords, each separate glacier receives its burden of material from the cliffs on each side of the fiord, and thus becomes loaded with earth and stones. The icebergs, therefore, carry away immense quantities, both lying on their surface and frozen in their lower parts. These are dropped as they melt. Thus, the land of Greenland is being cut down by glaciers and carried away by icebergs, and strewed all over the bottom of the Atlantic as far south as 50° to 40° north latitude. The materials thus dropped over the sea-bottom are similar to those borne by glaciers, and dropped in their pathway, except that they are carried much farther, and also that they are more or less sorted and stratified by dropping through water. Large blocks perched in insecure positions would not probably occur.

Therefore, smooth, striated, *moutonnéed* rocks, perched, angular blocks, and terminal moraines cannot be produced by icebergs, but are wholly characteristic of glaciers. The importance of this discussion will be seen when we come to speak of the Glacial epoch.

SECTION IV.—CHEMICAL AGENCY OF WATER.

It will be remembered that we divided the agency of water into mechanical and chemical. We have now finished the former, and are ready to take up the latter. Previous to doing so, however, there is a preliminary subject of great interest, viz., *underground waters.* And here we return again to the domain of familiar observation, for every student may observe for himself much that follows :

Underground Waters and Origin of Springs.

As already said (page 18), of the water which falls by rain and snow, a part runs off the surface, producing universal rain-erosion; another part sinks into the earth, and after a longer or shorter subterranean course, comes up again as springs, and joins the surface-waters to form the streams. Still a third part does not come up on the land-surface at all, but by subterranean passages finds its way to the sea. In some countries this third part is large. This is especially so if the country-rock be limestone or lava, for these rocks are affected with subterranean galleries and caves. In Florida, for example, rivers often disappear, ingulfed in the earth, and continue to the sea by subterranean passages. In shallow seas off such coasts places are known where fresh water comes up in large quantities, and ships may be supplied with drinking-water. Such submarine springs are known off the coast of Florida, the West Indies, the Hawaiian Isles, and the shores of the Mediterranean. There is still another part of subterranean water which, perhaps, is not rain-water, or, if so, is not *now* circulating like the others. As far down as the earth has been penetrated, perhaps below even the sea-bed, there is found rock-water, but not in flowing streams. This may be rightly called *volcanic water*, as it is probably concerned in volcanic eruptions.

Perpetual Ground-Water.—In passing downward from the surface we find the ground contains more and more water, until it becomes saturated and the water movable. The highest level at which the water is *always* movable is called the level of perpetual ground-water. It is deepest on the hilltops, comes nearer the surface on the slopes, and under favorable conditions may reach the

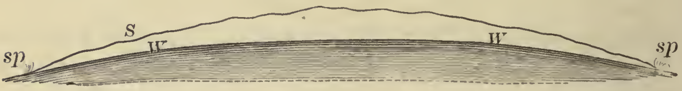

FIG. 35.—Diagram of perpetual ground-water. *S*, surface of ground; *WW*, ground-water; *sp*, *sp*, hillside springs.

surface near the bottom or in the valleys and issue as springs (Fig. 35).

Springs.—Springs are the issuance of underground waters, and wells are artificial springs. Often water is observed to ooze out on hillsides or at hill-bottoms, making a marshy spot. In such cases, if we examine, we shall usually find a reason for it in the fact that a water-bearing stratum of sand or gravel, underlaid by an impervious stratum of clay, outcrops at this point. Water falling on the hill sinks down until it reaches the impervious clay, and then flows out laterally (Fig. 36). These may be called *seepage-springs.*

Again: in other places, especially mountain-regions, we find strong or *bold springs.* Usually, in such cases, we may find a fissure through which the water comes up to the surface (Fig. 37).

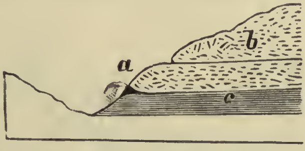

FIG. 36.—Hillside spring. *b*, sand; *c*, clay; *a*, spring.

In still other places, but only in countries where rocks of cavernous structure, such as limestone and lava, prevail, we sometimes find great *springs,* from which issue rivers of considerable size. Perhaps the most remarkable example is the "Silver Spring" of Florida. The river which flows from this celebrated spring is so considerable

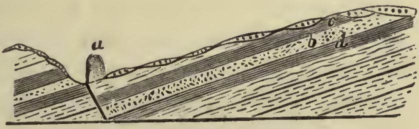

FIG. 37.—Fissure spring.

that small steamers go up the river and *into the spring*, and the cotton of the region is shipped at the Silver Spring landing. For fifty to sixty miles around, there are no surface-streams. The country-rock being here a very soft and cavernous limestone, the rain-water is all absorbed and finds its way by underground streams to the surface at Silver Spring. This spring is also celebrated as having probably the clearest water in the world.

Artesian Wells.—Ordinary wells are artificial seepage-springs. Artesian wells are artifical *great springs*, i. e., they are the tappings of underground streams which otherwise would have reached the sea without coming to the surface. In a level country, underlaid by regular strata which turn up and outcrop on mountains or hills (Fig. 38), we are almost certain to reach artesian water. In such cases, the pressure of water from the hills will cause the water to rise, not only to the surface, but often to spout as a fountain. Fig. 38 shows the conditions under which this will probably occur. There are few places where artesian water may not be reached by deep boring, though the conditions of abundant supply are by no means universal. The deepest artesian wells are those near Leipzig, 5,735 feet deep ; near Pittsburg, Pa., 4,625 feet ; at St. Louis, nearly 4,000 feet. Water from such great depths is always warm.

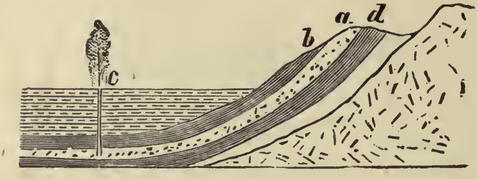

FIG. 38.—Artesian well.

Thus, then, rain-water falling upon the land returns to sea, whence it came, partly by surface drainage, partly by underground drainage. The relative proportion of these varies greatly in different countries, depending upon the nature and position of the rocks; but by far the larger part usually returns by the surface, being brought up by hydrostatic pressure. Only in limestone and in recent volcanic regions is the proportion returning by underground passages large.

Chemical Effects of Underground Waters; Mineral Springs.—We have seen that all rocks are changed into soils by the removal of their soluble portions. These are then taken up by percolating water and brought to the surface by springs, while the insoluble portions remain as soils. It is evident, then, that all springs contain mineral matters derived from the rocks. If the quantity be large, or the mineral rare and medicinal, then it is called a *mineral spring*. These are usually hot because of the great solvent property of hot water.

Limestone Caves.—Now, in most cases the proportion of insoluble matter is so large that the resulting soil is fully as bulky as the rock from which it was formed; there is, therefore, no vacant space left. But, in the case of limestone, the whole rock is soluble in water containing CO_2. Underground streams, therefore, dissolve out galleries and caves in their courses. Hence, irregular caves and galleries are found in limestone rocks in all countries. These are often of very great extent, the galleries being sometimes, as in the case of the Mammoth Cave, hundreds of miles long. The most celebrated in this country are the Mammoth Cave, Kentucky; Wyandotte Cave, Indiana; Wier and Luray Caves, Virginia; Nicojack Cave, Tennessee; and Bower Cave, in California.

In all cases they have been hollowed out by solution and by erosion, and therefore are, or have been, occupied by underground streams. Some are so still, as the Nicojack; some only partly, as the Mammoth Cave; some not at all. In all cases, they have been occupied in former times by much larger streams than now; in nearly all cases, instead of being hollowed out by solution, they are now being filled again by chemical deposit. When the waters were in abundance they dissolved; but, now that they are reduced to drippings, they deposit. The drippings from the roof form icicle-like *stalactites* (*a*); the drippings on the floor, the *stalagmites* (*b*); the runnings down the walls form *pilasters.* The stalactites, constantly growing in size and length, finally meet the stalagmites and form *pillars* (*c*), (Fig. 39).

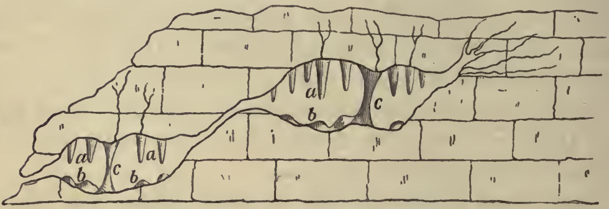

FIG. 39.—Section of limestone cave.

The variety and beauty of the forms produced by deposit in these caves are often marvelous. One of the latest discovered and most wonderful in this respect is the Luray Cave, Virginia, described in the "Smithsonian Report" for 1880. Fig. 40 is copied from this report.

The caves and galleries of lava are formed in an entirely different way, as will be explained hereafter under the head of Igneous Agencies (page 137).

Lime-Sinks.—In cases of soft, impure limestone, the undermining of the rock causes the surface to sink. Thus are formed the lime-sinks so common in Florida and some portions of Georgia.

Chemical Deposits in Springs.—We have seen that all springs contain mineral matters in solution. Some of these are deposited at the surface, and some not. The most important deposits are lime carbonate from carbonated springs, *iron oxides* from chalybeate springs, *sulphur* from sulphur-springs, and *silica* from alkaline springs.

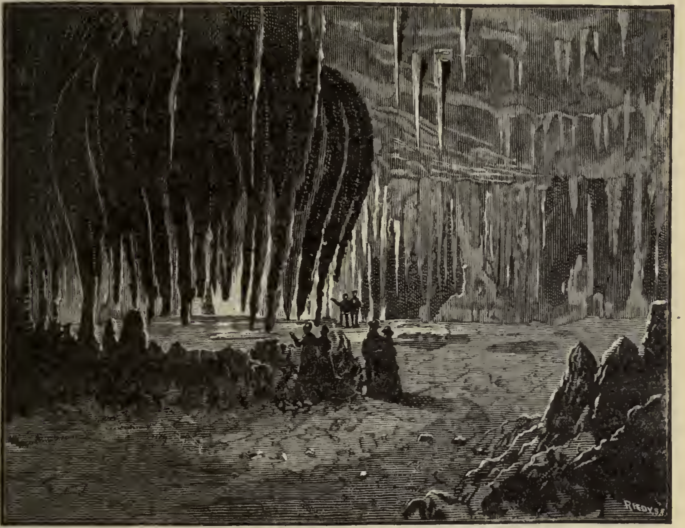

FIG. 40.—The Saracens' tent, Luray Cave.

Deposits of Lime Carbonates.—These deposits are in carbonated springs in limestone regions, and especially in volcanic countries. In order to understand why deposit occurs, the student must remember—1. That lime carbonate (limestone) is slightly soluble in water containing CO_2. 2. That up to a certain limit the solubility is proportioned to the amount of CO_2. 3. That the amount of CO_2 taken up by water is proportioned to the pressure. Now, besides the small quantity of CO_2 in air, and therefore in all meteoric water, there are also subterranean sources, especially in volcanic regions. Therefore, if water circulating deep in the interior, and therefore under heavy pressure, come in contact with subterranean sources of CO_2, it will take up a corresponding amount, and coming up to the surface, and the pressure being relieved, a portion of the CO_2 will escape, with effervescence. Thus are formed carbonated springs, often called *soda springs,* on account of their pleasant pungency, like the so-called soda water of the shops. Now, if such water, thus charged with CO_2, meets limestone, it will dissolve a proportionate amount of this substance. On coming to the surface, the pressure being relieved and the CO_2 escaping, the lime carbonate will be deposited about the spring and in the course of the issuing stream as long as the CO_2 continues to escape.

In this way immense deposits, several hundred feet thick and many miles in extent, are formed. If the deposits are regular and slow, the rock formed will be hard (*travertine*), but, if rapid and with escaping gas, it is spongy (*calcareous tufa*). If the water be free from coloring-matter, the stone is exquisitely white and fine; but if iron be present, it will be yellowish, buff, or brown. If the coloring-matter varies from time to time, the most exquisitely banded, striped, and clouded appearance results. Nothing can exceed the delicate beauty of these deposits in some cases. If the water, thus highly charged with lime carbonate, makes a cascade, every object on which the spray falls becomes covered with deposit. In Italy, advantage is taken of this property to make *facsimiles* of coins, medallions, etc. The stream from the spring is made to fall on lattice, which scatters the spray in all directions. The medallions are placed on shelves within reach of the spray, and quickly become incrusted. The removed crust, similarly placed, is used as a mold, in which, by deposit, a *facsimile* is made.

Examples of such deposits are found in all parts of the world. Perhaps the most beautiful occur in Italy, where exquisite works of art are made of them. But many examples are found in our own country. About the Old

Sweet and the Red Sweet Springs, West Virginia, and in the course of the issuing stream, a buff-colored travertine is deposited. About two miles below the Red Sweet the stream makes the Beaver-dam Falls. Here everything within reach of the spray—leaves, twigs, grass—becomes quickly coated with deposit. In California, the exquisitely banded *Suisun marble* is a deposit formed in earlier geological times. In *Yellowstone Park,* the deposits of this kind are very abundant, and assume strange and beautiful forms (Fig. 41).

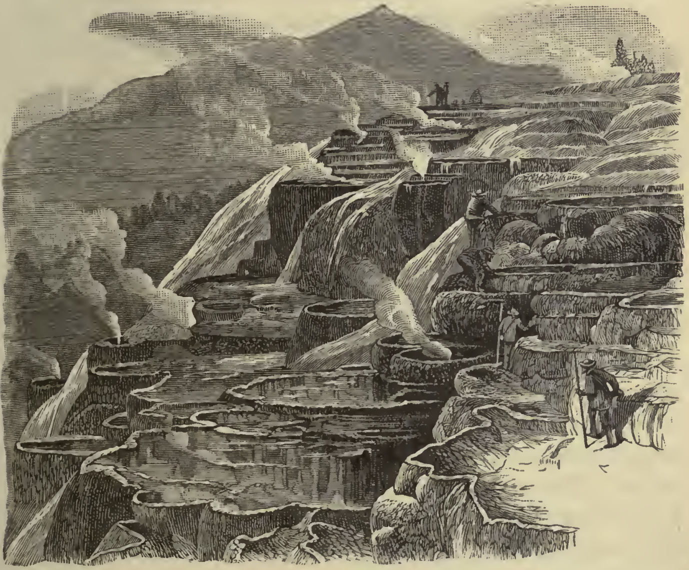

FIG. 41.—Deposits of lime carbonate, Yellowstone Park. (After Hayden.)

Deposits of Iron Oxide.—Iron is one of the most universally diffused of substances. In the form of carbonate and sulphate, especially the former, it is dissolved in the water of *chalybeate springs.* Every one must have observed that about such springs there is a reddish deposit ; in fact, such deposit is the usual sign of the existence of iron in the waters.

The explanation of the deposit is as follows : Iron has a powerful affinity for oxygen. As soon, therefore, as the water reaches the surface the iron exchanges CO_2 for oxygen of the air and forms a *peroxide*, which, being insoluble, is deposited. In regard to how the iron came in the solution, we shall speak again under Organic Agency.

Deposits of Sulphur.—A yellowish deposit is usually seen about sulphur-springs. These springs contain hydric sulphide (H_2S) in solution. The oxidation of this by the contact of air forms water and deposits sulphur ($H_2S + O = H_2O + S$).

Deposits of Silica.—Silica (quartz, sand, flint, etc.) is usually regarded as extremely insoluble, but it is soluble to a limited extent in alkaline carbonate waters, and the solubility increases with the heat. Now, alkaline carbonate waters are common in volcanic regions, and are often hot. Such hot alkaline springs take up silica in their subterranean course, and, coming to the surface, deposit abundantly, partly by cooling, mostly by drying. Perhaps the best example of such deposits is found at Steamboat Springs, Nevada. Here, over an area of half a mile long and a quarter of a mile wide, the whole surface is covered with a deposit of silica twenty feet thick, and over the whole area clouds of steam are seen issuing from many vents. The deposit takes a great variety of forms—sometimes a tufaceous material called sinter ; sometimes more solid and regularly banded ; sometimes milky-white chalcedony ; and sometimes white quartz like loaf sugar. Deposits of silica are found in all geysers. We shall, therefore, again speak of this under that head.

Chemical Deposits in Lakes.

Saline Lakes ; Salt Lakes.—Salt lakes are found only in dry climates. They are formed in two ways—

either, *a,* by indefinite concentration of river water in a lake without outlet; or, *b,* by isolation of a portion of sea water by movement of the earth's crust (upheaval of sea bed). The salt lakes scattered over the Nevada Basin—e. g., Pyramid, Winnemucca, Carson, Humboldt, and Walker Lakes, etc.—probably belong to the former class, for some of them are but slightly salt even yet. Great Salt Lake has been regarded as belonging to the latter class, but if it once had an outlet, as now seems certain, it must have been formed like all the other lakes in this region. The Dead Sea, from the composition of its water, is regarded as an example under the second class. The Caspian is usually regarded as an example under the first class, for, though it has apparently dried away from much greater dimensions, yet its waters are much less salt than those of the ocean. Nevertheless, there are some reasons for thinking that the Caspian was once connected with the Black Sea and with the Arctic Ocean.

Alkaline Lakes.—Saline lakes are of two principal kinds, *salt* and *alkaline.* All those mentioned above are salt. Alkaline lakes are rare; they are found in Hungary, Lower Egypt, and especially in Nevada and California. The largest of these are Lakes Mono and Owen, both in California. The waters of Lake Mono are a strong solution of sodic carbonate (sal-soda), with some carbonate of lime, borax, and salt. Lake Owen contains about equal parts of soda and salt. Salt lakes may be formed in either of two ways, but alkaline lakes in only one—viz., by indefinite concentration of river or spring water in a lake without an outlet. If in the river or spring water alkaline *chlorides* predominate, the lake will be *salt;* if alkaline *carbonates* predominate, it will be *alkaline.*

Borax Lakes.—These are still rarer than alkaline lakes. They are found only in Thibet and in California and Nevada. Borax lakes are of course formed only by concentration of spring water.

Conditions of the Formation of Saline Lakes.—Any lake will, in time, become saline *if it has no outlet*; but whether or not it has an outlet depends on the relation of *supply* by rivers and springs to *waste* by evaporation. If the supply exceeds the waste, the lake will rise until it finds an outlet, and remain fresh—i. e., the quantity of saline matter is so small as to be imperceptible to the taste. But if the waste be equal to or exceed the supply, so that the quantity of water is stationary or diminishes, then the salting process begins. Every drop of river or spring water coming into the lake contains some saline matter, however small, gathered from rocks and soils, and this is, of course, left in the lake. Thus there is a continual leaching of all the surrounding soils, and an accumulation of the leachings in the lake. It may take thousands or even hundreds of thousands of years, but in time the lake will become saline, and more and more so, until finally the point of saturation is reached and *deposit* begins.

I have taken the case of concentration of river water, but it matters not how the lake was originally formed; the same conditions will determine its saltness or freshness. For example, if a salt lake be formed by the isolation of a portion of sea water in the gradual upheaval of a continent, whether it remains a salt lake or whether it becomes fresh will depend on the conditions indicated above. If, for example, the sea bottom and contiguous land about the Golden Gate were elevated so as to separate the Bay of San Francisco from the Pacific Ocean, this bay would certainly become a fresh lake; for the amount of water coming into the bay is far greater than the waste by evaporation. This is shown by the fact that, although so fully connected with the ocean, the waters of the bay are far fresher than those of the sea. The water of the bay would therefore rise until it found an outlet to the sea, and then would commence a process of rinsing out by fresh water, until it would become entirely fresh. For the same reason, it is believed that the Black and Baltic Seas, if cut off, would become fresh, while the Gulf of California and the Mediterranean would not only remain salt, but would become more and more salt until they would deposit. Lake Champlain, as we shall see hereafter (p. 391), was once connected with the Atlantic. When first separated, it was of course salt, but by the continual pouring in of fresh water and pouring out of the mixture, the lake was gradually rinsed out and became fresh.

It is evident, then, that we ought to find saline lakes only in very dry climates; for, in most places, the rain falling on land-surface is far greater than the evaporation from the same, the excess finding its way to the sea by rivers. It is evident, also, that we ought to find every degree of salination of salt lakes. Lake Walker, Nevada, and Lake Tulare, California, are but slightly saline, while Great Salt Lake, Utah, is already saturated and beginning to deposit; and many examples of dried-up salt lakes are found all over Utah and Nevada. It is evident, again, that only the *last reservoir*, even of the same river water, will be salt. Thus the same water runs into Lake Tahoe, and thence through Truckee River into Pyramid Lake—but *no farther*. Lake Tahoe is deliciously fresh, while Pyramid Lake is salt. So, also, the same water runs into Lake Utah, and thence, through the River Jordan, into Great Salt Lake, but no farther. Lake Utah is fresh; Great Salt Lake is a saturated brine.

Why the Ocean is Salt.—The ocean is a reservoir without outlet. But the question of its saltness is a little different from that of salt lakes; for much of the rocks of the earth's crust was formed at the sea bottom and salted by the sea; and the salt is only regathered in salt lakes. Nevertheless there can be no doubt that the sea also got its salt from the rocks. The salts of the sea are the accumulated leachings of all Geological times.

Deposits in Saline Lakes.—We have seen that saline lakes occur only in dry climates. Furthermore, the climate of the regions where they occur has been for a long time, and still is, *growing drier*. The lakes have been, and are still, drying up, and many have entirely dried away. In the Basin region—i. e., the desert region between the Wahsatch and Sierra ranges—there are hundreds of such dried-up lakes. Now, from the time the point of saturation is reached until the lake is dried up, deposits of some kind must occur. These, of course, vary with the composition of the water, but the simplest are those formed by the drying up of an isolated body of sea water. What will take place in such a case is known by the artificial evaporation of sea water in the manufacture of salt. No deposit at all takes place until nine tenths of the water is evaporated. Then, as the point of saturation for salt is approached, first gypsum is deposited; after the whole of the gypsum is deposited, the common salt begins to deposit, and continues until nearly all is crystallized, and a dense mother liquor, or bittern, is left, containing the more soluble matters, especially magnesium chloride and sulphate.

In Nature the process is the same, except that it is complicated by mechanical deposits of silt (sand and clay). Until the point of saturation is reached, only mechanical deposits of silt take place, as in fresh lakes. Then gypsum will begin to deposit, but not continuously. In all such dry countries, all the rain that falls at all, falls in a few months of each year. The deposit of gypsum will alternate with mechanical deposits of mud or silt. The chemical deposits of gypsum will represent the dry season, and the mechanical deposits of silt the season of rains. When all the gypsum is exhausted, the common salt will begin to deposit, and this will alternate in the same way with silt, until finally only a mother liquor is left, which is very difficult to dry away.

Now, all these stages are actually found in Nature. Great Salt Lake has reached the saturation point, and is beginning to deposit. The Dead Sea has deposited largely, and its composition is that of a half exhausted mother liquor. Lake Elton, on the Russian steppes, has deposited all its salt, and its composition is that of a wholly exhausted mother liquor. Borings about the shores of Lake Elton show an alternation of silt and salt many times repeated, such as we have described. The bearing of these facts on the explanation of what are called *salt-measures* will be seen when we come to treat of these.

In cases of saline lakes formed by the accumulation of the waters of rivers and springs, the deposits are far more complicated. The deposits found in the dried-up lakes of Nevada consist of common salt, lime carbonate, soda sulphate, soda carbonate, soda borate (borax), and soda lime borate (ulexite).

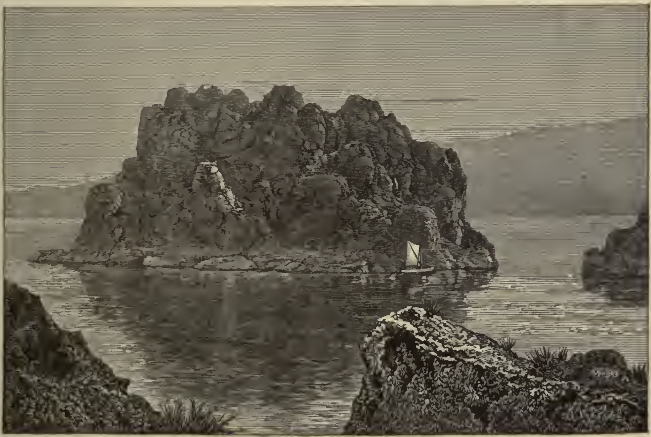

FIG. 42.—An island of tufa in Pyramid Lake, Nevada.

In alkaline lakes, like Mono, immense quantities of lime carbonate are depositing now, apparently from hot springs containing lime, coming up in the bed of the lake. These deposits take on curious coralline forms, which are very characteristic. Similar rough coralline forms are seen all about the margin and in the shallow water of this lake, looking at a distance like the dead stumps of an old forest. They show a greater extent of the lake at one time than now. Immense deposits of a similar kind are found in many parts of Nevada, and mark the places of dried-away lakes (Fig. 42).

CHAPTER III.

ORGANIC AGENCIES.

ORGANIC agencies are less powerful than aqueous in modifying the surface of the earth; yet, even in this respect, they are of no mean importance, since enormous beds of limestone are formed by this means. But their true importance is perceived when we remember that organisms are the most delicate indicators of physical conditions, and therefore of the changes through which the earth has passed. Organic remains or fossils are, as it were, the characters in which the history of the earth is written.

The subject may be best treated under four heads, each having a special application in explaining some important point in the history of the earth, viz.: 1. *Vegetable accumulations,* to throw light on the formation of coal and lignite. 2. *Iron accumulations,* to throw light on the great beds of iron-ore, found in the strata of earlier geological times. 3. *Lime accumulations,* to explain the formation of limestones. 4. *Geographical distribution of species,* to throw light on the geographical diversity of species in earlier epochs, and on the laws of succession of organic forms in the history of the earth—i. e., the laws of evolution.

The phenomena under all these heads can be observed by each one for himself; but it must be remembered that nearly all geological causes are very slow in their operation, and, therefore, the phenomena are not forced upon our attention, but must be looked for by intelligent, everwatchful observation. It is for this reason that geological phenomena are peculiarly adapted to cultivate the *habit* of observation.

SECTION I.—VEGETABLE ACCUMULATIONS.

Peat-Bogs.

Definition.—Every one knows that, under certain conditions, especially a moist climate and imperfect drainage, and in certain spots where moss, rushes, and other water-loving plants grow, there is found a black, carbonaceous mud, often many feet deep. A surface-crust is formed on the interlacing roots of many kinds of plants, beneath which is a tremulous mass of semi-liquid matter. On the surface-crust men or animals venturing, sometimes break through, and are ingulfed and perish. Such carbonaceous mud is called peat, and the places where it accumulates, *peat-mosses* or *peat-bogs.*

Peat-bogs are most common in cool, moist climates. A large part of Ireland, Scotland, Norway, Sweden, and Northern Europe generally, is covered with them. They cover, also, large parts of New England, and especially of Canada. In California, though a dry climate, an imperfect peat is found, covering large areas on the Lower Sacramento and the San Joaquin Rivers. These are the "*tule-lands.*" In tropic and semi-tropic countries, accumulations of peat are not so common, but are on a grander scale. The peaty accumulations there are overgrown, not by moss and rushes and shrubs, but by great swamp-trees. In these countries we have not so many peat-bogs, but a few great *peat-swamps.* Examples of these are found in the Great Dismal Swamp of Virginia and North Carolina, and in the great peat-swamps of the river-swamp and delta of the Mississippi.

Structure and Composition of Peat.—Beginning at the surface, we have in a peat-bog first the living vegetation and the undecomposed remains of the recently dead. As we pass down, the remains become older, and therefore more and more decomposed, and darker in color, until, at sufficient depth, it is a black mud, structureless to the naked eye, though still revealing vegetable structure to the microscope. In composition it is mainly carbon, with variable proportions of the hydrogen, oxygen, and nitrogen of the original plants. It is a disintegrated vegetable matter, which has lost much of its gaseous elements, and therefore with an excess of carbon. It is therefore a good fuel, and is extensively cut and used for this purpose, either simply dried or, better, made into a cake by hydraulic pressure.

Antiseptic Property.—Peat has a remarkable power of preventing or retarding decomposition. Logs and stumps have been found buried fifteen to twenty feet in peat, and therefore probably hundreds and even thousands of years old, which are still in a sound condition, and even fit for timber. Bodies of men and animals have been found with even the flesh preserved, though changed into adipocere. According to Lyell, the body of a man, *clothed in coarse hair-cloth,* was found in an Irish bog; and in a bog in Lincolnshire, the body of a woman, with skin, nails, and hair preserved, and with *sandals on the feet.* The *skeletons* of men and animals thus preserved are much more common; and even the skeletons of extinct species have been found in a perfect condition and unpetrified. The finest specimens of the mastodon have been obtained from old bogs in New York, New Jersey, Ohio, and Missouri.

Mode of Accumulation.—Remembering the antiseptic property of peat, its mode of accumulation is easily understood. In forests, a layer of mold a few inches thick accumulates on the soil from decomposition of the annual leaf-fall. This will not thicken indefinitely, because the rate of complete decomposition quickly equals the rate of addition. But, if abundant water be present, then the peculiar change takes place by which peat is formed, and the antiseptic property of the peat prevents complete decomposition, and the vegetable matter accumulates without limit. Thus, a peat-bog represents the accumulated remains of thousands of generations of plants. Every year adds to the ancestral funeral-pile, and the peat-ground rises higher and higher, until, although commencing on a low spot, it may rise above the immediately surrounding region, and, when swollen by rains, may even burst and deluge the surrounding country with black mud. In the case of the great peat-swamps of southern regions, the accumulation is entirely in this way—i. e., by growth *in place.* But, in small peat-bogs in hilly countries, the peat accumulates also by the driftage of surface-mold. In this case, the accumulation is much more rapid, but the peat is less pure.

Lastly: As a peat-swamp commenced on a low spot, it was often, at first, a shallow pond or lake, and the peaty matter encroached upon it from the margin. Thus, there may be found in the center of the peat-swamp a small remnant of the original lake. The Great Dismal Swamp is an excellent example. This swamp, forty by thirty miles in extent, is overgrown with great swamp-trees so thickly that there is little or no underbrush. The peat accumulates by the annual fall of leaves and branches only, and the rate of thickening is, therefore, probably very slow. The peat is very black, pure, and structureless, and is from twenty to thirty feet deep. The surface of the swamp is decidedly higher than the immediately

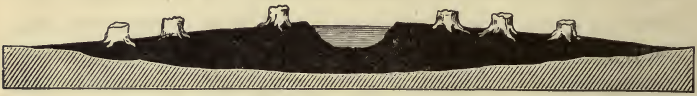

FIG. 43.—Ideal section across the Great Dismal Swamp.

contiguous country. The central lake, which is seven miles in diameter, is probably the remnant of a once larger lake, as just explained. Fig. 43 is an ideal section illustrating these facts.

Rate of Growth.—In some cases the increase of peat deposits is rapid. In Germany, bogs are known which have formed since the Roman invasion ; for Roman roads are traced beneath them, and stumps and logs of trees, felled by Roman axes, and even the axes themselves, have been found at the bottom, covered with from ten to fifteen feet of peat. The bogs have been formed by the obstruction of drainage caused by felling the trees. Similarly, many of the bogs of England were formed at the time of the Norman conquest, by the felling of forests, in order to exterminate bands of Saxon outlaws. On the other hand, in the great peat-swamps, where the accumulation is strictly by growth in place, the increase must be very slow, perhaps only a few inches per century. It is evident, then, that the rate is very variable, and therefore no safe estimate of age can be based on thickness.

Section of a Peat-Bog.—A section of a bog reveals the following : 1. Beneath is usually a clay on which are often found the stumps and roots of the preceding forest-growth. The under-clay seems necessary to hold the water without which peat will not form. 2. Above this a mass of black, carbonaceous matter, structureless to the eye, but showing its vegetable origin to the microscope. 3. This passes by gradations through imperfect peat into the recently fallen leaves and branches, and the still growing vegetation. Now, imagine this covered with mud or sand, deeply buried, and subjected to great pressure for ages, and we can easily see that it would become converted into a *coal-seam*, with its *under-clay* full of roots and stumps, and its *roof-shale* full of impressions of leaves and flattened stems.

Alternation of Peat with River-Silt.—We have said that peat occurs in the river-swamps and deltas of great rivers. It is easy to see, therefore, how peat deposits may at long intervals be flooded and covered with river-silt, and again reclaimed and covered again with peat vegetation, perhaps many times. Now, in cutting into the delta of the Mississippi, several layers of peat, with interstratified silts, are found. The resemblance of this to a series of coal-seams on a small scale is very striking. It is by observing things now going on that we find the key for interpreting things which occurred in earlier geological times. We shall apply these principles in Part III.

Drift-Timber.

But there is another way in which vegetable accumulations occur now, and therefore may have occurred in previous epochs. Great rivers in heavily wooded countries, like the Mackenzie and the Mississippi, in flood-times, bring down large quantities of drift-timber gathered in their upper courses, and accumulate them in the form of rafts at their mouths. These natural rafts are often of great extent. One, at the entrance of the Atchafalaya, near the head of the delta of the Mississippi, was in 1838 ten miles long, a quarter of a mile wide, and many feet thick. Such rafts become finally water-logged, sink, and are covered up in a river-silt. Then they are slowly changed into a brownish, cheesy substance, and doubtless finally into lignite or coal. Now, in cutting into the delta deposit of the Mississippi, layers of drift-timber are met with which is undergoing this change. This also may throw light on the formation of coal and lignites.

SECTION II.—IRON ACCUMULATIONS.

Every one must have observed that in certain boggy spots, on hillsides, or on plains at the foot of hills, are found reddish deposits of iron mixed with earth. This form of iron is called *bog iron-ore.* It is by observing such phenomena, and trying to find out how they are produced, that we may expect to throw light on the formation of the great iron-beds which are found in the strata of earlier geological times. More commonly the iron is in the form of hydrated ferric oxide ($2Fe_2O_3,3H_2O$) but sometimes of ferrous carbonate ($FeCO_3$).

Mode of Formation.—Iron has a very strong affinity for oxygen, as is shown by the rapid rusting of iron when exposed to the weather. But this is true, not only of metallic iron, but also of ferrous oxide, and of ferrous carbonate. In all cases it runs rapidly into the condition of highest oxidation—viz., *ferric oxide.* But, although iron has so strong an affinity for oxygen, yet a *portion* of the oxygen of ferric oxide will be taken away from it by the superior affinity of organic matter in a state of decomposition. Thus, ferric oxide (Fe_2O_3) in contact with decomposing organic matter will be reduced to ferrous oxide (FeO), which then readily unites with carbonic acid (CO_2), always present in meteoric waters, and forms ferrous carbonate ($FeCO_3$). Ferrous carbonate is feebly soluble in water containing CO_2.

Now, iron is a very abundant substance, but, on account of its affinity for oxygen, it exists most naturally only in the form of ferric oxide ; in which state, therefore, it is almost universally diffused as a red or yellow coloring-matter of soil and rocks. In this state, though abundant, it is unavailable to man. But organic matter, in a state of decay, is everywhere on the surface of the ground. This is dissolved by rain-water, and sinks into the earth. Therefore, all subterranean water contains organic matter in solution. Such water, percolating through red soils or red rocks, first reduces the iron to *ferrous* oxide, then to ferrous *carbonate,* then takes it into solution—i. e., washes it out of the soil or rock, leaving these decolorized, then comes to the surface, as springs containing iron carbonate (chalybeate springs). This is where we took it up (page 75). Then, as was there shown, it again comes in contact with air, gives up CO_2 and retakes oxygen, and is reconverted into ferric oxide, which, being insoluble, is deposited.

The above is a complete explanation of the accumulations of *ferric* oxide. In this case the organic matter is consumed, i. e., changed into CO_2 and H_2O, in doing the work of reduction and solution, and there is nothing to prevent the iron from returning to the condition of ferric oxide. But, if there be an *excess of organic matter,* as peat, for example, in the place where the deposit occurs, then the *iron will be deposited as ferrous carbonate,* because it can not exist in the form of ferric oxide in the presence of decaying organic matter. This is a sufficient explanation of deposits of iron-carbonate.

Familiar Illustrations.—We have gone so far into this explanation because the effects of water containing CO_2 in leaching out the coloring-matter of soils may be observed on every hand, and thus, therefore, afford an excellent field for cultivating the observing power of the pupil.

1. If a dead stump, with roots ramifying in red soil, be examined, it will often be observed that the soil is bleached immediately about each root. This is because water containing organic matter, running down the root, leaches out the red coloring-matter of the soil.

2. In every railroad-cutting, or other excavation in red soil, it will be observed that the walls of every fissure in the soil, through which water from the surface descends, will be bleached for a little distance on each side.

3. Red clays exposed to view by excavations, natural or artificial, are often variegated or marbled with irregular streaks and spots of deeper or lighter color. This is produced by *irregular* percolations of water containing organic matter.

4. Even in the most intensely red-clay regions, in wooded places the surface-soil, for a foot or more in depth, is bleached. Water containing organic matter from the surface leaches out and carries down the coloring iron to the subsoil.

5. The clay of uplands may be yellow or red, but the clay of swamp-lands is always *bluish*. This is because ferric oxide, which is the red or yellow coloring-matter, can not exist in the presence of organic matter, abundant in swamps, but is reduced to ferrous carbonate and its color destroyed. But, if such blue clay be burned to brick the organic matter is destroyed, the iron is peroxidized, and the *brick is red*.

SECTION III.—LIME ACCUMULATIONS.

Lime accumulations are made mainly by *corals* and by *shells*. We shall take up the subject under these two heads.

Coral Reefs and Islands.

Although corals do not make reefs in temperate regions, and therefore the process can not be observed by every one, yet, for many reasons, the subject is of peculiar interest, both popular and scientific. Coral reefs are of peculiar *popular interest*—1. On account of the strange forms and gorgeous beauty of the animals which inhabit them. 2. On account of the gem-like beauty of the islands which form on them. 3. Because a large area is added to the habitable land-surface by the agency of corals; and especially, 4. Because the largest continuous body of land thus added is on our own coast, viz., in Florida. 5. Because of the great dangers to navigation, especially on the coast of Florida, resulting from the presence of these reefs. The considerable town of Key West owes its existence wholly to the wrecking business.

There are also peculiar points of *scientific interest.* To the geologist they are of the extremest interest—1. As agents producing immense accumulations of limestone. 2. As evidences of crust movements on a magnificent scale. These points will be brought out as we proceed.

It is a common idea—an idea which has passed into popular literature, and is difficult to eradicate—that corals and coral reefs, like the hills and galleries of ants, are built slowly by the coöperative labor of millions of little *insects.* It becomes necessary, therefore, to explain somewhat fully the manner in which a reef is really formed.

A Simple Polyp.—Fig. 44 represents an ordinary soft polyp (*Actinia—sea-anemone*), somewhat simplified, such as may be seen clinging to rocks or piers on our sea-shores almost anywhere. Their structure is diagrammatically shown in section (Fig. 45). As seen by these figures the creature may be compared to a hollow, fleshy cylinder, closed at both ends like a yeast-powder can. The lower may be called the *foot*-disk, the upper the *mouth*-disk. The edge of the mouth-disk is surrounded by hollow tentacles, *t t,* which open into the hollow cylinder. In the center of the mouth-disk is the mouth, *m,* and below it hangs the stomach, *s,* reaching about half-way down. At

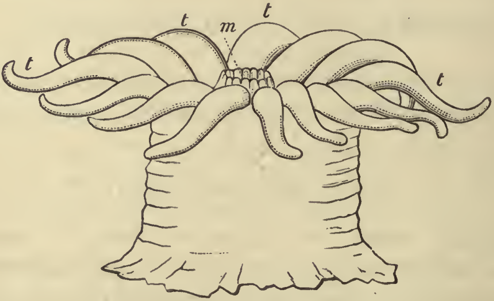

Fig. 44.—Simplified figure of an actinia.

the lower end of the stomach is the pylorus, which may be opened and shut like a second mouth. Running from the outer wall, and converging toward the axis, are many partitions, *p p,* some of which reach the stomach and hold it steadily in the axis, but below the stomach terminate in free, scythe-like edges. These converging partitions divide the body cavity into a number of triangular apartments, which, however, are in free communication with each other below the stomach. Besides the main partitions spoken of, there are very many smaller ones which do not reach so far as the stomach. The whole structure may be briefly summarized by tracing the course of the food. Food is taken by the tentacles, put into the mouth, and passes into the stomach. After digestion, whatever is refuse is thrown back through the mouth, and the digested food is dropped through the pylorus into the general *hall* below the stomach, and there mixed with sea-water and circulated through all the apartments.

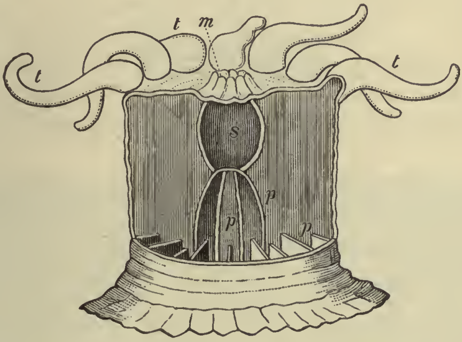

Fig. 45.—Ideal section, vertical and horizontal, showing structure : *t*, tentacles ; *s*, stomach ; *p*, *p*, partitions.

Simple Coral, or Stone Polyp.—Now, a simple coral has a similar structure, except that stony matter (lime carbonate) is deposited in the lower part as high as about the region of the stomach, as shown in Fig. 46. When the animal seems to disappear, it only withdraws the soft upper parts within the stony lower part. But the stony material is everywhere *within* the living organic matter and covered. When the living organic matter is taken away, as in *dead* corals, then we have only the radiated structure of the lower part in stone. This is well shown in Fig. 47, *a* and *b*. The corals which form reefs, however, are individually extremely small.

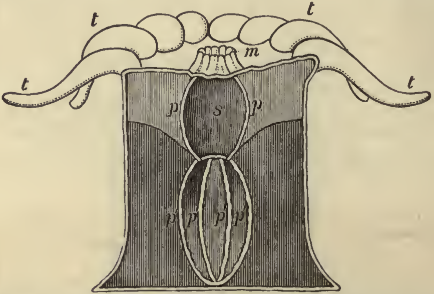

Fig. 46.—Ideal section of a single living coral. The shaded portion contains carbonate of lime.

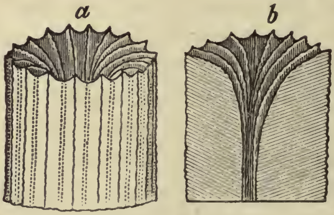

Fig. 47.—*a*, stony part of a single coral ; *b*, section of same, showing structure.

Compound Coral, or Corallum.—Many lower animals, like plants, have the power of reproducing by buds. If the buds separate, they form distinct individuals ; but if they remain attached, then a compound animal is formed, composed of many individuals, united together precisely as a tree is formed of many buds, each of which is in some sense an individual, and capable of independent life. In the compound coral each bud has its own tentacles, mouth, stomach, partitions, and other organs necessary for life, and yet all are organically connected, and each feeds for all. There is, therefore, a sort of individuality in the aggregate, but a more decided individuality in each bud.

The form of the aggregate depends on the mode of budding. If the buds grow into branches, then there is formed a *tree-coral* (Fig. 48); but if the buds do not separate, but remain connected to their ends, and form new buds in the intervening spaces, then they form a *head-coral* (Fig. 49). There are all gradations between these extremes. Coral-trees are often six to eight feet high, so that one may literally climb among the branches. Coral-heads form hemispherical masses fifteen to twenty feet in diameter. In either case the aggregate consists of hundreds of thousands of individuals; in either case, also, the living organic matter is confined to the superficial portion, one quarter to one half an inch thick. As in

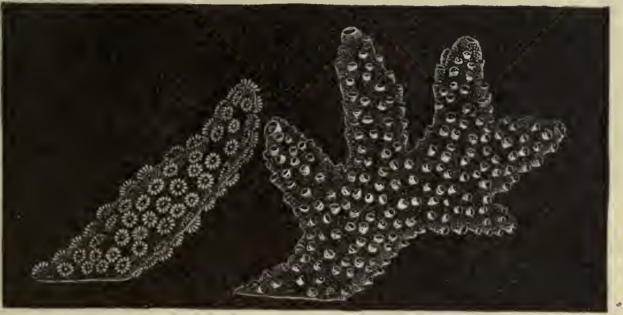

Fig. 48.—Madrepora, a tree-coral.

case of a tree, so in corals, life passes continually outward and upward, leaving the middle parts dead, and, in fact, wholly composed of mineral matter (lime carbonate), retaining, however, the peculiar structure given it while permeated with living matter.

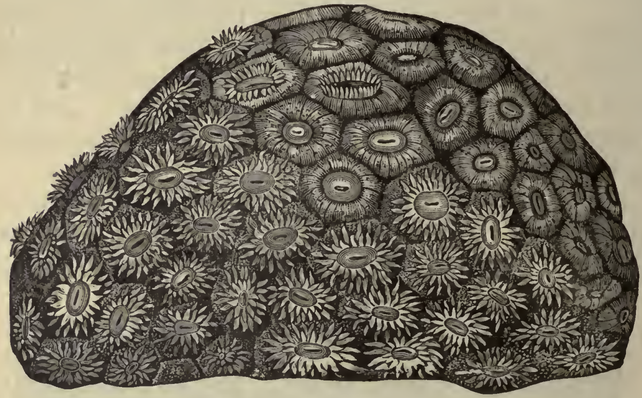

Fig. 49.—Astrea, a head-coral.

Coral Forests.—Corals, however, *reproduce also by eggs.* These are formed within, below the stomach, extruded through the mouth, and having, like the eggs of many lower animals, the power of locomotion, swim away and settle to the bottom, where, if conditions are favorable, they form single corals, which, by budding, soon form coral-trees or coral-heads. In this way a coral *forest* or grove is formed, and spreads in all directions as far as favoring conditions allow (Fig. 50).

Coral Reefs.—But coral forests are not yet coral reefs. These are formed by the growth and decay on the same spot of countless generations of coral forests. Each generation in its death leaves its limestone behind ; and thus the coral ground rises or is built up without limit except by reaching the sea-level. As a peat-bog is formed by the accumulated remains of successive generations of plants growing and dying on the same spot, so a reef is similarly formed by successive generations of corals. As peat-ground may rise above the surrounding country, so a coral reef rises far above the surrounding sea-bottom. As peat represents so much carbon taken from the air and added to the ground, so a reef represents so much carbonate of lime taken from the sea-water and added to the sea-bottom. The limestone thus formed by the broken remains of corals cemented together is called the *reef-rock.* Thus a reef is a submarine bank composed of reef-rock, crowned with the present generation of living corals.

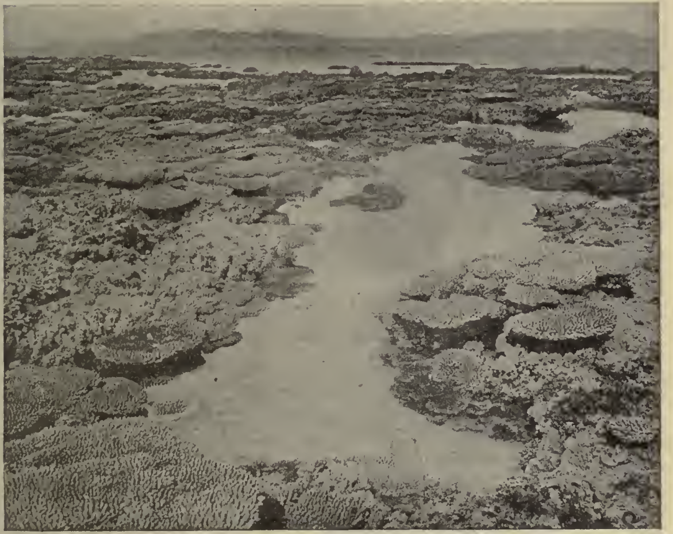

FIG. 50.—Corals in the Great Barrier Reef, Australia.

Coral Islands.—But even coral reefs are not yet coral islands, since corals can not grow above the sea-level. Coral islands are made by the action of waves. Waves will form islands on any kind of submarine bank when the water is shallow enough for the waves to touch and chafe the bottom. When, therefore, the reef rises nearly to the surface, the beating waves will break off coral-trees, coral-heads, and even masses of the reef-rock. Great masses are thus rolled up on the inner side of the reef, and form a nucleus about which other masses gather. Among these larger masses smaller masses are thrown, then finely comminuted coral limestone (coral sand) is sifted among these, and the whole is cemented into a solid rock by carbonate of lime in the sea-water. The island rock, therefore, is *a breccia of coral limestone,* as shown in Fig. 51. The island thus formed is at first barren rock; but, slowly, seeds are brought by waves and wind; it becomes covered with vegetation, and inhabited by animals and by man.

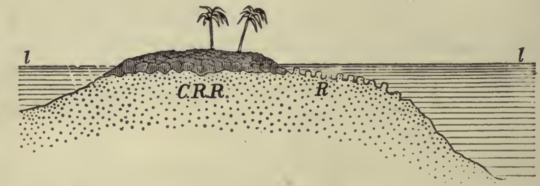

FIG. 51.—Ideal section across a coral island; *l*, *l*, sea-level; *R*, living reef; *C.R.R.*, coral reef-rock.

Thus we have traced the whole process, and find no evidence of purpose or will, much less the admirable virtues of perseverance and industry, often attributed to them. It is a pity to spoil a moral; but truth is the best moral.

Conditions of Growth.—Reef-building corals do not grow over the whole sea-bottom, nor in all oceans. They are strictly limited by certain conditions:

1. They will not grow where the mean winter temperature of the ocean is less than 68° Fahr. This condition confines them mostly to the tropics. The most notable

apparent exception to this is in the North Atlantic. On the coast of Florida and the Bahamas reefs occur as far as 28° and on the Bermudas as far as 32° north latitude. But this is because the temperature of 68° is carried northward by the warm waters of the Gulf Stream.

2. Reef-building corals will not grow at a greater depth than about one hundred feet. This condition confines them to submarine banks, and especially to shore lines. In tropic seas corals build all along the shore, and as far out as the depth will allow. Hence results the usual *linear* form of reefs.

3. They require, also, clear salt water, and are killed by fresh water and by mud. They will not grow, therefore, along flat, muddy shores where the waves chafe the bottom and stir up mud. Also, if a reef is formed along a shore-line, there will be breaks in the reef off the mouths of rivers, the corals being prevented from growing there partly by the freshness of the water, and partly by the mud brought down by the river.

4. Corals grow best where they are beaten by the waves—viz., on the outer portion of the reef. Some species, indeed, love the still water on the inner side of the reef, but the strong, reef-building species thrive under the effect of the dashing waves, and will even build upward in the face of waves that would wear away a granite wall. The corals are broken, indeed, and worn, but growth more than makes up for the wear. This is because the crowded life on the reef, both of corals and of animals of all kinds feeding on the corals, rapidly exhausts the water of its oxygen and replaces it with carbonic acid, and thus renders it unfit to support life. But the chafing and foaming of the breakers discharges the CO_2 to the air and restores the oxygen. It is exactly like the ventilation so necessary for air-breathing animals.

All these conditions refer only to *reef-building* species.

Some species of corals live at great depths and in high latitudes.

Description of Pacific Coral Reefs and Islands.—There are in the Pacific two very distinct kinds of islands—viz., volcanic islands and coral islands. The former are high, bold, rocky, and often of considerable size; the latter low, wave-formed. We will suppose the preëxistence of volcanic islands, and proceed to show how coral reefs and islands are formed about them.

Pacific reefs, then, are of three principal kinds—viz., *fringing* reefs, *barrier* reefs, and *circular* reefs or *atolls.*

1. Fringing Reefs.—These grow along any shore-line, but the most common and interesting are those about volcanic islands. Suppose, then, a high volcanic island in the midst of the sea. Around such an island corals will build, limited outward by increasing depth, limited inward by shore-line and upward by sea-level, thus forming a submarine platform clinging close to the island like a

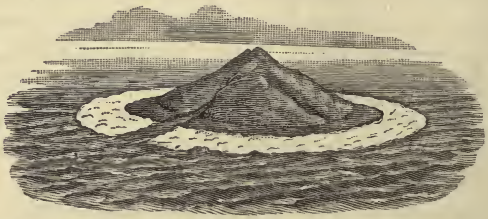

Fig. 52.—Perspective view of volcanic island and fringing reef.

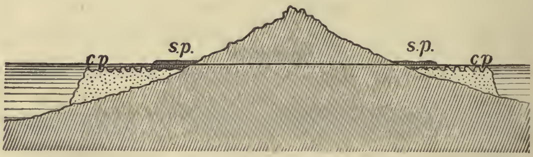

Fig. 53.—Ideal section of volcanic island and fringing reef; *s.p.*, shore platform; *c p*, coral platform.

fringe. The existence and extent of such a reef are revealed by the snow-white sheet of breakers which surrounds the island like a snowy girdle (Fig. 52). Off the mouths of large rivers breaks in the reef will occur. Fig. 53 is an ideal section showing the coral platform, *c p, c p.*

So much for the agency of corals. The waves now break off fragments from the outer part of the reef and pile them up on the inner part against the land, and thus form a low, level *shore platform, s.p., s.p.,* above the sea-level. Thus we have first the slope of the volcanic island; then the shore-platform of coral *débris;* then the submarine platform of living corals; and, finally, the deep water. In this case there is *no coral island,* but only a *coral addition* to the volcanic island.

2. Barrier Reefs.—About the volcanic island there may be little or no fringing reef, but at a distance of five, ten, or fifteen miles away, in deep water, there rises a line of reef like a great rampart surrounding the island, and, as it were, protecting it from the attacks of the sea.

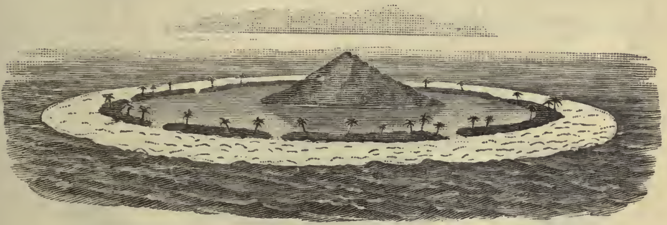

FIG 54.—Perspective view of volcanic island and barrier.

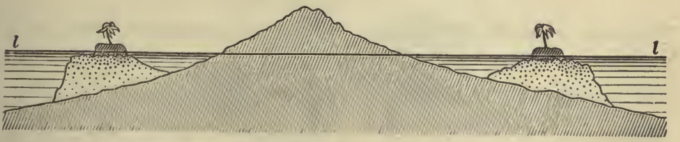

FIG. 55.—Section of volcanic island and barrier.

The position of the reef is shown by a snowy girdle of breakers, within which, like a charmed circle, there is calm sea in the wildest storm. Between the reef and the island there is a ship-channel, often twenty or thirty fathoms deep. Through breaks or tidal ways in the reef, ships enter and find good harbor in the channel. If it were not for the action of the waves, this would be all, but the beating waves form little *coral islands* on the reef, so that, instead of a continuous snowy girdle, it is such a girdle gemmed on the inner edge with a string of green islets. By sounding it is found that the inner slope of the reef is gentle, but the outer slope is very steep, and rapidly passes into abyssal depth. All these facts are shown in the perspective view, Fig. 54, and the section, Fig. 55.

3. Circular Reefs, or Atolls.—These are the most remarkable of all. In this case there is no volcanic island or preëxisting land of any kind apparent, as a nucleus for the growth of corals. The reef seems to have been built up from abyssal depth, in an irregular circular form, inclosing a *lagoon* of still water in the midst (Fig. 56). The position of the reef, *r*, *r*, is shown by a circle of snowy foam inclosing and protecting a harbor of still water. Through breaks in the reef-circle ships may enter and find safe anchorage. The lagoon is ten, twenty, thirty, or even fifty miles in diameter, and thirty or

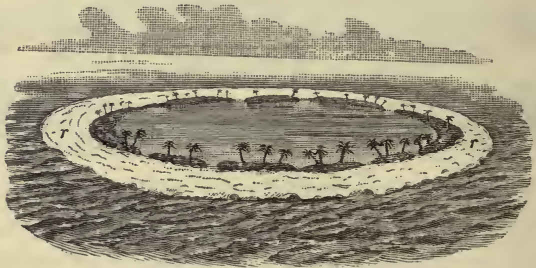

FIG. 56.—Perspective view of an atoll.

forty fathoms deep. By sounding it is found that the inner reef-slope is gentle, but the outer very steep, so that at a distance of a mile more than a mile depth has been found (Fig. 57). Thus far, the action of corals alone. Now add the action of waves, and the snowy ring is gemmed on the inner edge with small green islets. All these facts are shown in Figs. 56 and 57.

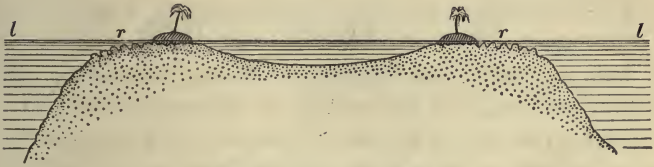

Fig. 57.—Section of an atoll.

4. Closed Lagoons and Lagoonless Islands. — In the typical atoll the reef-circle is large, and only dotted with small islets, but in small atolls the land is more continuous (Fig. 58, *a*), or entirely continuous, but the

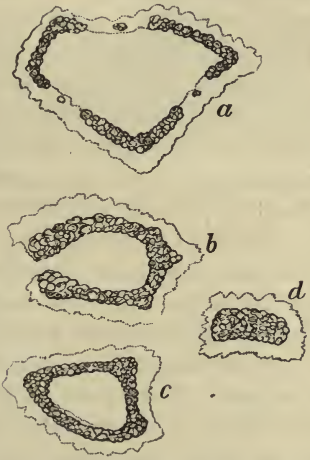

Fig. 58.—Map view of closed lagoons and lagoonless islands.

lagoon open to the sea on one side (Fig. 58, *b*), or the lagoon may be entirely *closed* (Fig. 58, *c*), or the ring may close in upon itself so as to abolish the lagoon (Fig. 58, *d*). These are so different from the typical atoll that they may be considered a fourth class.

Theory of Barriers and Atolls.

Fringing reefs need no theory. Corals, finding the condition of suitable depth along the shore, build upward to the sea-level and outward to the depth of one hundred feet, and thus form a coral platform clinging to the original island. But barriers seem at first sight to form far from land in abyssal depth ; and atolls seem to form in deep sea without any island-nucleus. These facts seem to violate the conditions of coral growth. How are they explained ? The most probable explanation was first given by Mr. Darwin.

Darwin's Subsidence Theory.—According to Darwin, every reef began as a fringe, and would have remained so if the floor of the ocean had remained steady. But, in all the region of barriers and atolls, the ocean-floor has slowly subsided, carrying all the volcanic islands with it downward. Now, if the subsidence had been more rapid than the coral ground could rise by accumulations of *débris* of successive generations, then the corals would have been carried below the depth of one hundred feet and drowned. But the subsidence was not faster than the coral ground could be built up. Therefore the corals building upward, as it were, for their lives, kept their heads at or near the surface. But the reef, building up *nearly* at the same place, while the volcanic island grew smaller, it is evident that the latter would be separated more and more from the reef. When the island was down *waist-deep*, the reef was a barrier ; when down *head-under*, it became an atoll, the reef representing *nearly* the outline of the original base of the volcanic island. We said *nearly*, but *not* perfectly. The corals do not build up perpendicularly, but in a steep slope. The barrier, and much more the atoll, is therefore smaller than the original fringe. If, therefore, the subsidence continues, the atoll will grow smaller and smaller, the separate islets will close together, join each other, and finally close the lagoon. Then the lagoon will close in upon itself and form the lagoonless island, and, last of all, this also will probably disappear.

As corals grow best on the outside of the reef, they will not occupy the channel formed by recession of the volcanic island; or, if they do, they are soon drowned out by subsidence. The channel, however, in case of barriers, or lagoon in case of atolls, will be partly filled by *débris* carried into it in both cases from the reef, and in the case of barriers also from the volcanic island. Fig. 59 is an ideal section embodying all these facts. In this figure, for convenience of illustration, instead of the sea-bottom sinking, the sea-level is represented as rising.

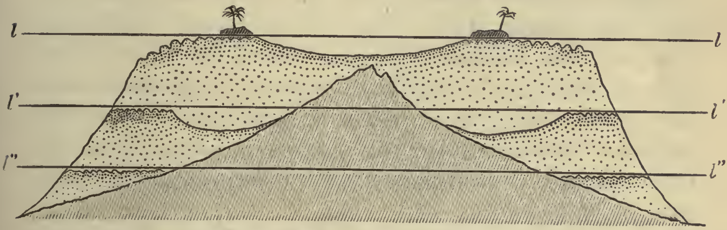

FIG. 59.—Ideal section diagram showing the formation of an atoll; *l''*, *l''*, sea-level when reef was a fringe; *l'*, *l'*, when it was a barrier, and *l*, *l*, the present sea-level.

Murray's Theory.—The subsidence theory, however, is not now universally accepted. Agassiz first showed, by study of the reefs of Florida in 1851, that barriers are formed without subsidence. Murray, traveling in the same region as Darwin, concluded that both atolls and barriers may be formed without subsidence. He supposes that atolls are built up by corals on banks previously formed by other agencies, the corals growing only on the outer margin of the bank, because they find the best conditions of growth there. Barriers, he supposes, are fringes separated from the encircled island by dying out of the corals on the landward side and extension on the seaward side of the reef.

It is probable that atolls and barriers are formed in several ways, but under present lights it is not improbable that many, if not all, atolls are formed as Darwin supposes. We will assume that every atoll marks the place of a drowned volcanic island.

Area of Subsidence.—The area of the subsiding sea-floor is 6,000 miles long and 3,000 miles wide. It is probably not less than 12,000,000 square miles, or greater than the whole North American Continent.

Area of Land Lost.—This must not be confounded with the sinking area. The sinking area is the whole sea-floor, over millions of square miles; the land known to have been lost is only the volcanic islands which once overdotted this area. This is, of course, small in comparison. Estimated by the circles inclosed by atolls, Dana makes it 50,000 square miles. It is doubtless, however, much more than this. For—1. This estimate takes no account of barriers, but all the area between a barrier and the shore-line is also lost. Now, along the Australian coast, for 1,100 miles, there is a barrier thirty to forty miles distant. This alone would make 33,000 square miles lost for this one barrier. We may with confidence, therefore, double the estimate. But, 2. Atolls themselves, as already shown, are smaller, and closed lagoons and lagoonless islands very much smaller than original volcanic islands. And, 3. In the middle of the coral region there is a blank area of several million square miles, in which there are no islands of any kind. Many islands probably went down here and left no sign, because they went down too rapidly and the corals were drowned. Putting all these facts together, it seems probable that several hundred thousand square miles of volcanic land have been lost. Of this only a small fraction has been recovered by the action of corals and waves.

Amount of Vertical Subsidence.—This may be roughly estimated in many ways: 1. Soundings a little way off barriers have reached 2,000 feet, and off atolls 7,000 feet. 2. The average slope of volcanic islands of the Pacific is about 8°, but, taking it even as low as 5°, a barrier ten miles from shore would indicate a subsidence of 4,500 feet. ($DB = AD \cdot \tan A$.) But barriers are found at much greater distances than ten miles. 3. The average height of volcanic islands of the Pacific in non-subsiding areas is 6,000 to 10,000 feet. Now, every atoll represents such an island, entirely submerged, and every closed lagoon the same deeply submerged. But it is very improbable that none of these reached the average of those remaining. Taking all these facts together, it is probable that the extreme subsidence is not less than 10,000 feet.

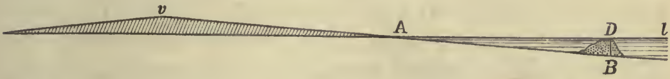

FIG. 60.—*v*, volcanic island; *A*, shore line; *D*, place of barrier; *AB*, slope of bottom, 5°.

Amount of Time Involved.—It is evident that the rate of sinking can not have been greater than the rate of coral ground-rising; otherwise the corals would have been drowned. Again, the rate of ground-rising is far less than the rate of coral-prong growth. If the annual growth of all the prongs were taken, ground to powder, and strewed over the area shaded by the coral branches, it would give the annual rising of the ground. It is evident that this would be very small in comparison with the growth of the prongs. In addition to this, it must be remembered that large spaces of a coral reef are bare. Taking all these things into consideration, it has been estimated that one quarter to one half inch per annum is a large estimate of rate of ground-rising. The subsidence can not be greater and may be much less than this. At this rate a subsidence of 10,000 feet would require 250,000 to 500,000 years. The whole of this, however, must not be accredited to the present geological epoch. It probably extends back into the Tertiary.

Geological Application.

There are several points in the preceding discussion which throw important light upon the structure and history of the earth. 1. We have here examples of limestone rock, formed by coral agency over millions of square miles, and in places many thousand feet thick. For not only is limestone formed on the *site of the reefs* (reef-rock), but the fine coral *débris* is carried by waves and currents and strewed over the whole intervening space. We find thus a key to the extensive deposits of limestone formed in previous geological times. 2. *The kind of rock* formed also deserves attention. The *reef-rock* is, in some parts, a *coral breccia;* in other parts it consists of rounded granules, cemented together (oölite). In the deep sea of the intervening spaces, the bottom ooze is a *fine coral mud,* which, dried, looks much like chalk, and by some has been supposed to be indeed the modern representative of chalk; but more probably, it hardens into a compact limestone. Now, in limestones of previous geological epochs, we find similar structures; i. e., extensive fine limestone, with areas of coarse coral breccia or of oölites. We are thus able to determine the position of old coral seas and the lines of old coral reefs, even though they are now occupied by mountain-ranges, as in the case of the Jura Mountains (Heer). 3. Lastly, we have here examples of movements of the earth's crust on a grand scale—on a scale commensurate with the formation of continents and ocean-bottoms. The phenomena of coral reefs show a down-sinking of the mid-Pacific bottom of several thousand feet, and over an area of many million square miles. This has been going on through later geological times, and is probably still progressing. Now, so wide-spread a downward movement must have its correlative in an upward movement somewhere else. It seems probable that we find it in the upheaval of the western half of the American Continent, both North and South. It is well known that during the whole later Tertiary, even to the present time, the western part of North America, especially the plateau region, has been slowly rising, the extreme rise being nearly 20,000 feet. As it rose, the general erosion became greater and the cañons cut deeper and deeper. So that the down-sinking of the Pacific bottom, the upheaval of the plateau region, and the cutting of the wonderful cañons of that region, are probably all connected with each other.

REEFS AND KEYS OF FLORIDA.

The reefs of Florida deserve separate and special treatment, not only because they are on our own coast, but also because they are in some important respects entirely peculiar: 1. In the Pacific, barrier-reefs are always the result and the sign of subsidence. In Florida, on the contrary, we have barrier-reefs where there has been no subsidence. 2. In the Pacific, corals do not *add* to the previously existing land-surface; on the contrary, they only *recover* a small fraction of a lost land-surface. But in Florida there has been apparently no loss, but a *constant growth* of land-surface under the action of corals, assisted by waves and other agents, as we shall presently explain. Attention has not been hitherto sufficiently drawn to the entire uniqueness of these reefs.

Description of Reefs and Vicinity.—Fig. 61, *A*, is a map of Florida, its keys, reefs, etc., and Fig. 61, *B*, is a section of the same along the line *N S*. The southern coast of Florida, *a a*, is a ridge of limestone, twelve to fifteen feet high, inclosing a swamp called the Everglades, *e*, only one to two feet above the sea-level, covered with

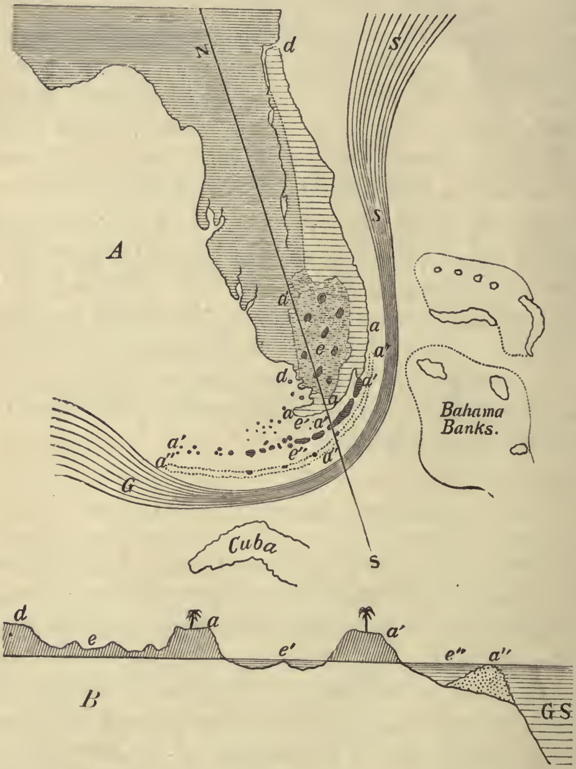
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FIG. 61.—Map and section of Peninsula and Keys of Florida. In both, *a* = coast; *a′* = keys; *a″* = reef; *e* = everglade; *e′* = shoal water; *e″* = ship-channel; *GS* = Gulf Stream.

fresh water, overgrown with vegetation, and overdotted with higher spots, called hummocks. Going south from the coast, the next thing that attracts attention is a line or string of limestone islands (keys) *a′ a′*, stretching in a curve from Cape Florida to the Tortugas, a distance of one hundred and fifty miles. Between these and the southern coast is an extensive shoal, almost a mud-flat, navigable only to small fishing-craft. The width of this shoal is thirty to forty miles. It is overdotted with small, low, mud islands, overgrown with mangrove-trees, and entirely different from the true keys. Outside of the line of keys, and separated from it by a ship-channel, five to six miles wide and three to four fathoms deep, is a continuous line of living reef, *a″ a″*. On this, by the action of the waves, a few small islands have commenced to form. Outside of all sweep the deep waters of the Gulf Stream, *G S*.

Formed by Coral Agency.—Now, the whole area thus described is a recent coral formation, and has been added to Florida in recent geological times. The proof of this is complete.

First: On the living reef, islands have just commenced to form. Some are yet only a collection of large coral fragments, the nucleus of an island. Some are more compacted by smaller fragments thrown in among the larger. Some are small but perfect islands—i. e., coral, sand, and mud have been thrown upon and completely buried the large masses. But none of these are yet clothed with vegetation, much less inhabited by animals and man. Next come the larger inhabited islands of the line of keys. On cutting into these, the same structure as described above is revealed. Undoubtedly these are a string of wave-formed coral islands, and here was once a line of living reef; but the corals have long ago died, because cut off from the open sea by the formation of another reef farther out. Next comes the southern coast. Examination of this reveals the same structure precisely. Here, then, was the place of a still earlier reef.

Brief History of the Process.—There was, therefore, a time when the north shore of the Everglades (*d*, section, Fig. 61, *B*) was the southern shore of Florida. At that time the place of the present southern coast was occupied by a living reef. On this reef coral islands were formed, which gradually coalesced into a continuous line of land, the shoal water between it and the mainland was filled up, and the whole added to the mainland; the southern coast being transferred to its present position, and the shoal water, with its mangrove islands, changed into the Everglades, with its hummocks. In the mean time, however, i. e., while the present southern coast was still a line of keys, another reef was formed in the place of the present line of keys, and the former have therefore died. This new reef in its turn was converted into a line of keys, which will eventually coalesce into a continuous line of land, the shoal water will be filled up, and form another Everglade, with its hummocks, and the coast-line be transferred to the present line of keys. But already another line is formed, and the previous line is dead; already the process of key-formation has commenced. We can not doubt that eventually, but probably only after many thousands of years, the Peninsula of Florida will extend even to the present living reef. Farther than this it can not go, for the deep water of the Gulf Stream is close at hand, and forms its impassable boundary.

Farther northward, the extent of the coral formation is less known, but it has been found on the eastern coast as far as St. Augustine. The middle and western part of Florida, as far as the north shore of the Everglades, is probably older. The line *d d* (Fig. 61, *A*), therefore, probably marks out the area which has been added to Florida by the agencies described. The area already added is probably not less than 12,000 to 15,000 square miles, and the area which will be added at least half as much more.

Coöperation of Other Agencies.

We have seen that the reefs of Florida are unique. It seems certain, therefore, that they were formed under unique conditions. The things to be accounted for are—1. The constant growth of land; and, 2. The formation of barriers where there was no subsidence.

1. The constant growth of land southward shows that there was a continual extension southward of the conditions of coral-growth, i. e., of *moderate depth.* In other words, there must have been a gradual extension southward of the submarine bank, on the edge of which the corals grew. If there had been a preëxisting bank, obviously the corals would have grown as only *one* reef on its outer edge; the formation of *successive* reefs, one beyond the other, proves that the shallow bank on which they grew must have extended successively in that direction.

Thus much seems certain, but the cause of the extension is more uncertain. It is probable, however, that the bank was formed and extended by sedimentary deposit by the Gulf Stream.*

Thus, then, the extension of the Peninsula of Florida in recent times has been the result of the coöperation of several agencies: 1. The Gulf Stream built up from deep-sea bottom a bank, and extended it by the same process. 2. The corals took up the work by forming successive barrier-reefs farther and farther south as the necessary condition of moderate depth extended. 3. The waves then took up the work and converted the line of reef into a line of keys, and finally a line of land twelve to fifteen feet high. 4. The shoal waters between the successive lines of keys and the mainland was filled up by coral *débris* carried inward from the reef and keys, and southward from the previously formed land, and the mainland was thus extended to the keys.

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* At one time the sediments were supposed to be *mechanical sediments* from the Gulf rivers, especially the Mississippi. But now they are believed to be *organic* sediments, partly brought by the Gulf Stream from other coral banks, e. g., the Yucatan bank, but mainly formed in place by the growth of successive generations of deep-sea shells; the Gulf Stream bringing only the conditions of heat and food necesary for rapid growth.

2. Barrier-reefs without subsidence may be accounted for thus: From the manner in which, by this view, the bases of the coral reefs were formed, viz., by sedimentation, there must always have existed a very soft, shallow sea-bottom. Along such a shore-line a *fringing reef could not form,* because the chafing waves *stir up the mud.* But at a distance from shore, where the water is a hundred feet deep, and the waves no longer touch the bottom, a line of reef would form, limited on the one side by the muddiness and on the other by the increasing depth of the water. This would be in form a barrier-reef, but wholly different in significance from those of the Pacific.

Shell Limestone.

Lime is constantly carried to the sea by rivers, and yet is the sea-water not saturated. This is because the lime in sea-water is constantly being drafted upon by animals to form their shells and skeletons. These remain after their death, accumulate as lime-deposits, and harden into limestone. We have already spoken of coral limestone, but other animals besides corals form limestones, and some make other kinds of deposits besides lime. Besides corals, the most important are shell-deposits. We shall treat these under two heads, *Molluscous Shells* and *Microscopic Shells.* And here we would again invite the personal observation of the pupil.

1. Molluscous Shells.—These inhabit mostly shallow water, and therefore accumulate mostly along shore-lines, and may be observed by all who keep their mental eyes open. Each generation takes lime from sea-water, and leaves it as shell on the bottom. These, therefore, accumulate until deposits of enormous thickness and extent are often formed. Sometimes the accumulated mass may consist of one species, as in oyster-banks; sometimes of many species. The deposit may be purely shelly, or shell mixed with mud, or mud with a few imbedded shells. Again, on *exposed shore-lines* the shells will be broken or even comminuted, and on quiet shore-lines, as in bays or harbors, they will be perfect. These accumulations are gradually hardened into limestone (Fig. 62).

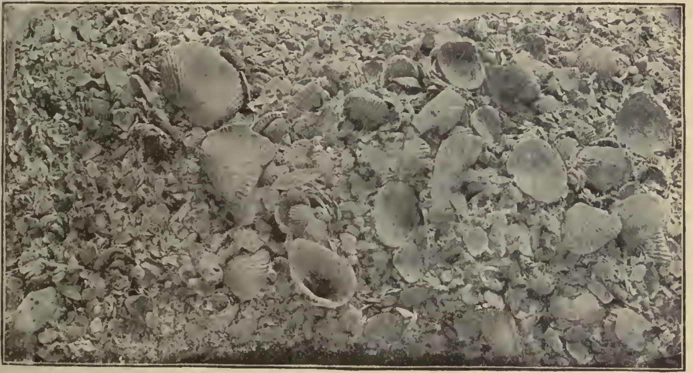

FIG. 62.—Modern shell limestone. (After Scott.)

Application.—Now, all these different kinds of limestone or shell rock are found far away from present seas and high up in the mountains. We are thus often able to trace out the shore-lines of previous geological times, and determine not only the species which then lived, but also the conditions under which they lived.

2. Microscopic Shells.—These are some of vegetable, some of animal origin; some fresh water, some marine; some composed of silica, some of lime carbonate. The two most important kinds are silicious fresh-water deposits of vegetable origin, and lime carbonate, deep-sea deposits of animal origin.

Fresh-Water Deposits.—It is well known that still waters swarm with microscopic unicelled plants. Most of these have no shells and leave no deposit. But one kind —the diatoms—form shells of silica. Generation after generation of these leave their shells until deposits of great thickness and extent are formed. In any clear and sluggish stream, if we examine with the microscope the slime on the stones at the bottom, we shall find living diatoms. These are carried by freshets into ponds, lakes, or seas into which the streams empty. Usually the mud carried with them is so abundant that they will not be detectable in the deposit thus formed. But in large, deep, clear lakes, like Lake Tahoe, beyond the reach of sedimentary deposit, the deep bottom-ooze is found to be composed wholly of the accumulated shells of diatoms. Also in the hot springs of California and in the pools formed by the accumulation of these waters, diatoms are

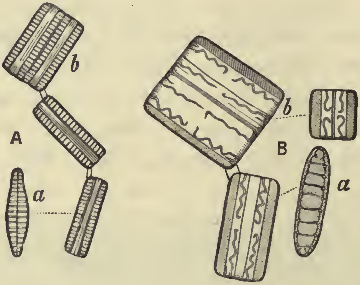

Fig. 63.—A, diatoma vulgare: *a*, side view of frustule; *b*, frustule dividing itself. B, grammatophora serpentina: *a*, front and side view; *b*, front and end view of dividing frustule.

very abundant, and deposits of these shells are formed comparatively rapidly.

Application.—In many countries, and nowhere more abundantly than in California, is found a soft, white, very light and friable earth, often many feet in thickness and many square miles in extent, which, under the microscope, is seen to consist wholly of shells—some perfect, some broken—of diatoms. It is only by the study of deposits now forming that we may hope to understand the conditions under which these remarkable deposits were formed.

Deep-Sea Deposits.—Many deep-sea explorations have been recently undertaken by the governments of Europe and the United States. From these we learn that the deep-sea ooze is almost everywhere a fine white mud, which dried looks like chalk, and under the microscope is seen to be mainly composed of the carbonate-of-lime shells—some perfect, more broken, most of all comminuted—of Foraminifera (a low form of animals). The most abundant form is *Globigerina* (Fig. 64), and therefore this ooze is often called *globigerina ooze.* Among these are scattered silicious shells of diatoms and several other kinds of shells, animal and vegetable. All of these probably live at the surface, and on their death drop to the bottom. So that we may imagine a continual drizzle of these shells falling to the bottom. These deposits are certainly of enormous extent, and probably of great thickness.

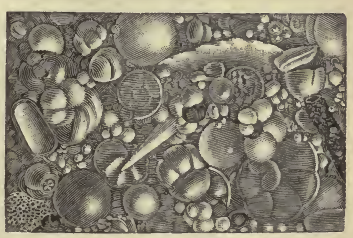

FIG. 64.—Foraminiferal ooze. × 13. (Agassiz after Murray and Renard.)

Application.—There is one geological stratum which bears a striking resemblance to this deep-sea ooze, viz., the chalk of England, France, the interior of Europe, and our own western plains. The origin of this very peculiar stratum will hereafter be discussed in the light of these facts.

SECTION IV.—GEOGRAPHICAL DISTRIBUTION OF SPECIES.

No one can go to a foreign country, or even a distant part of our own country, as, for example, from the eastern to the western coast, without being struck with the great difference in the *native* animals and plants. If such a one has been trained to observe, he will see that nearly all the species are entirely different. As a broad, general fact, every country has its own native species, differing more or less conspicuously from those of other countries. The *laws* of this distribution and its *causes* have recently attracted much attention, and are a subject of very great interest. We can only give the briefest outline.

Faunas and Floras.—We shall hereafter frequently use the terms fauna and flora, and must therefore define them. The whole group of animals inhabiting one place is called its *fauna,* and of plants its *flora.* Thus, we may speak of the fauna and flora of New York, or Illinois, or Oregon. But science cares nothing for such arbitrary limits—it deals only with *natural* boundaries. A natural fauna or flora is a *natural* group of animals or plants in one place, differing conspicuously from other groups in other places, and separated from them by natural boundaries, geographical or climatic. Among the climatic conditions limiting faunas and floras, perhaps the most important is *temperature,* and we shall therefore speak of this first. Again, plants, being fixed to the soil, are more strictly limited than animals, and we shall therefore illustrate the laws of distribution first by them. Again, temperature conditions change in *elevation* above the surface, and in *latitude.* We take the former first.

Botanical Temperature Regions in Elevation.—For this we take a high mountain, near the seashore in tropical regions, because we find there *all* the regions (Fig. 65). In going up such a mountain, from sea-level, *l l*, we pass through, — 1. A *region of palms*, so called because of the abundance of palms and palm-like forms, such as bananas, tree-ferns, etc.; 2. A region of hard-wood, or ordinary foliferous trees; 3. A region in which pines and pine-like trees predominate; 4. A *treeless region*, in which are only shrubs, herbs, and grasses; and 5. A plantless region, or region of perpetual snow. These regions, although we have separated them by lines, of course graduate insensibly into each other. The second region may often be subdivided into a region of evergreens and a region of deciduous hard-woods.

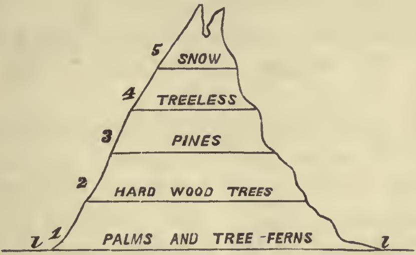

Fig. 65.

Botanical Temperature Regions in Latitude.—Now, since the above regions are determined wholly by temperature, and since a similar decrease of temperature is found in going from the equator to the poles, we ought to expect similar regions in latitude. And such we find. In going from the equator to the poles we find—1. A region of *palms*, corresponding to the *tropic* zone; 2. A region of *hard-wood* trees, corresponding to the *temperate* zone; 3. A region of *pines* and

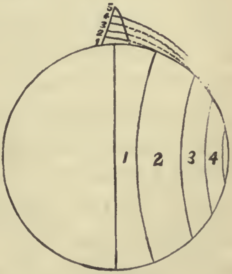

Fig. 66.

pine-like trees and birches, corresponding to *subarctic* and *arctic* zones; 4. A *circumpolar* region of *shrubs* and *grasses;* and, 5. Perhaps a plantless or nearly plantless region at the pole of cold. Here, again, No. 2 may be subdivided into a *warm*-temperate region of evergreens, and a *cool*-temperate region of deciduous trees. Here, again, also the regions graduate insensibly into each other.

We have been speaking thus far of sea-level or near sea-level. Of course, if a mountain in any latitude rises to perpetual snow, we will have on its sides all the temperature regions, except those south of it. Thus, in ascending the Sierra Nevada we have a temperate region (No. 2) at base, a subarctic region (No. 3) half-way up, and a circumpolar region (No. 4) at the summits.

Completer Definition of Regions.—1. All organic forms will spread in all directions as far as physical conditions and the struggle for life with other species will allow. The area over which they thus spread may be called their "*range.*" Now, the range of one species may be much greater than that of another, because more hardy; but the range of a species is always more restricted than its *genus*, for when the species can go no farther, another species of the same genus will continue the genus. For the same reason the range of a family is greater than that of its genera, etc. Thus, for example, in going up the Sierra we find the range of pines extend from 2,000 to 10,000 feet above sea-level, but the genus is represented by a succession of species of much more restricted ranges. We find, first, the *nut*-pine (*Pinus Sabiniana*), then the *yellow*-pine (*P. ponderosa*), then the *sugar*-pine (*P. Lambertiana*), then the *tamarack*-pine (*P. contorta*), and, last, the *mountain*-pine (*P. flexilis*). Hereafter we shall speak mostly of species.

2. We have said that the several temperature regions graduate insensibly into each other. We will now explain

in what sense this is true. Species, then, come in gradually on the borders of their range, reach their highest development in number and vigor about the middle, and pass out gradually in number and vigor on the other border, other species taking their place, and the two ranges overlapping on their borders. Thus, in Fig. 67,

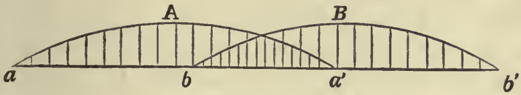

FIG. 67.

a a' is the north and south range of species A, and *b b'* of species B—the height of the curve the number and vigor of the individuals, and *b a'* the overlap of ranges.

3. But in *specific character* there is no such gradual passage of one species into another—no evidence of transmutation of one species into another, nor of derivation of one species from another. From this point of view species seem to come in at once in full perfection, remain substantially unchanged throughout their ranges, and pass out at once on the other border, other species taking their place as if by substitution, not transmutation. It is *as if* each species originated, no matter how, somewhere in the region where we find them, and then spread in all directions as far as physical conditions and struggle with other species would allow.

We can best make this plain by illustrations: The sweet-gum or liquidambar-tree extends from the borders of Florida to the banks of the Ohio. It is most abundant and vigorous, indeed, in the middle regions, and dying out on the borders, where it is replaced by other species: but is everywhere the same species, unmistakable by its five-starred leaf, winged bark, spinous burr, and fragrant gum. Again, the Red-wood (*Sequoia*) ranges from southern California to the borders of Oregon. It may be most vigorous in the middle region—it may decrease in vigor and number on its borders; but in all specific characters, wood, bark, leaf, and burr, it is the same throughout. The study of species, *as they now are,* would probably not suggest, certainly could not prove, the theory of their *origin by derivation or transmutation.*

4. Temperature regions shade into each other. But this is so only where no barriers exist. If there be barriers, such as an east and west mountain-chain, or sea, or desert, then on the two sides of the barrier the species will be very distinct and without gradation by overlapping. Thus, north and south of the Sahara, and north and south of the Himalayas, there is a marked and, as it were, a sudden change of species. It is, again, *as if* the species originated each in its own area and spread, but were prevented from mingling and overlapping on their borders by the barrier.

5. Again, although there are similar temperature regions on tropical mountains and in high latitudes—and these latter are also repeated north and south of the equator—yet the species are always different in the three cases. This is because the torrid zone is a barrier preventing migration. It is, again, *as if* species originated each in its own place, but were prevented from reaching similar temperature regions elsewhere by the existence of impassable barriers.

Zoölogical Temperature Regions.—Animal species are limited by temperature, like plants, and therefore also exist in temperature zones; but they can not be arranged in the same simple way, evident even to the popular eye —i. e., great classes corresponding to great zones. It is true that, if we compare extremes, viz., polar with tropical regions, we find a conspicuous contrast determined by temperature, certain great families being characteristic of each—as, for example, among mammals, the great pachyderms, the elephant, rhinoceros, hippopotamus, and the great cats, lions, tigers, jaguars ; among birds, toucans, parrots, trogons, ostriches ; among reptiles, crocodilians and pythons ; and among corals, the reef-builders, characterizing the tropics ; while the musk-ox, white bear, seals, walrus, ducks and geese, characterize the polar regions—yet we can not make a zonal arrangement of *families* as easily as we can with plants. But, confining our attention to species or even genera, animal forms are subject to the same laws as those of plants : 1. All animal species are limited in range ; 2. The range of species is more limited than that of genera, and of genera than that of families, etc.; 3. Contiguous ranges graduate into each other by overlapping, the species intermingling and coëxisting on the margins ; 4. Each species reaches a maximum of number and vigor in middle regions and dies out on the borders ; 5. But in specific character they seem to remain substantially the same throughout their range, and do not change or transmute into other species on the borders ; 6. Physical conditions may limit their range, but do not seem to change them into other species, though varieties may be formed in this way ; 7. Here, again, it is *as if* species originated, no matter how, in the places where we find them, and have spread in all directions as far as physical conditions and struggle with other species would allow. All that we shall say hereafter will apply equally to animals and plants.

Continental Faunas and Floras.—If there were no barriers to the spread of species around the earth on the same zone, there can be no doubt that they would thus spread, and faunas and floras would be arranged in a series of temperature zones from the equator to the poles, containing the same species all around. But the oceans are impassable barriers between the continents, and therefore the faunas and floras of different continents are substantially different. It is, again, *as if* they originated on the continents where we find them, and have been prevented from spreading and intermingling by the impassable barrier of the ocean. Even apparent exceptions, when examined, confirm the law, as we now proceed to show.

Fig. 68 is a north-polar view of the earth, and 1, 2, 3, 4, 5, are the temperature zones so often referred to. Now, commencing with Nos. 4 and 5, the species in the Eastern and Western Continents are substantially the same, for the lands of the two continents approach each other in these zones so nearly that they may be considered as one. There is no barrier to the spread of species all around the pole. But when we come to No. 3, and still more to No. 2, the difference of species is almost complete, and many genera are also different—and that, not because the physical conditions are unsuitable; for European species introduced in our country do so well that they often kill out our own native species. Nearly all useful and noxious species have been thus introduced. They were not here when America was discovered only *because they could not get here.*

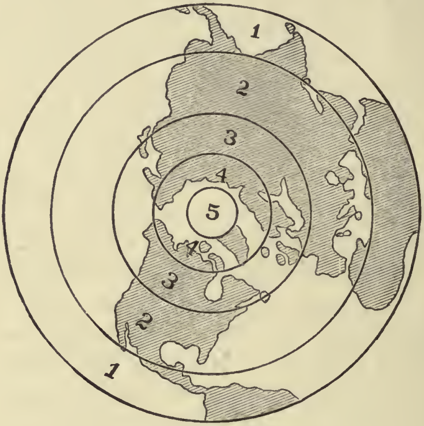

FIG. 68

We said the difference is *almost* complete. There are, therefore, some exceptions, but these only confirm the principles on which the rule is founded. They are of three kinds: 1. *Hardy or widely migrating species.* Some hardy species range through No. 3 into No. 4, and these may pass over from continent to continent. Some birds, like the Canada goose and mallard duck, migrate in summer to No. 4, and thence in winter southward in both continents. 2. *Introduced species,* which have become wild. 3. *Alpine species,* mostly of insects and plants. It is a curious fact that species of plants and insects, isolated on the tops of high mountains near the snow-line, are similar to each other on the two continents, and also similar to Arctic species. This latter fact gives the key to the explanation. The geological epoch immediately preceding the present (glacial epoch) was characterized by extension of Arctic conditions southward even to the shores of the Mediterranean and the Gulf of Mexico. At that time, therefore, Arctic species occupied all Europe and the United States. As the cold abated, Arctic species mostly went *northward* to their present home in the Arctic zone. But some followed the receding Arctic conditions *upward* to the tops of mountains, and were left stranded there, both in Europe and this country.

In No. 1 the species on the two continents are still more markedly different, the difference extending even to families and in some instances to orders. Thus, for example, among plants, the cactus order is confined to America. Among animals, the great pachyderms, e. g., elephants, rhinoceroses, hippopotamuses, also the camels, horses, and tailless monkeys, are confined to the Old World, while the sloths, the armadillos, the prehensile-tailed monkeys, the whole family of humming-birds (of which there are over four hundred species), and the family of toucans, are confined to the New.

South of the equator the continents do not again approach, and therefore the fauna of Africa and South America remain very different even to Cape Colony and Fuegia.

Subdivisions.—Continental faunas and floras are again subdivided in longitude, more or less completely, by barriers in the form of north and south mountain-chains. Thus the fauna and flora of the United States are subdivided by the Rocky Mountain and Appalachian chain into three sub-faunas and floras, an Atlantic slope, a Mississippi basin, and a Pacific slope. The difference between these is *strictly in proportion to the impassableness of the barriers.* Thus, between the Atlantic slope and the Mississippi basin the difference is very small, because the Appalachian chain is low and may be overpassed ; but the Pacific slope fauna and flora are almost wholly peculiar. Almost the only exceptions are strong-winged birds, like the turtle-dove, the turkey-vulture, the large blue heron, etc. In many cases the species are very similar and yet different. The meadow-lark and the yellow-hammer are examples. Similarly the Ural Mountains separate a European from a northern Asiatic fauna and flora. These subdivisions are perhaps more marked in case of plants than animals. The spread of plants is passive (dispersal), the spread of higher animals also by migration.

Special Cases.—Isolated islands, and in proportion to the degree of their isolation, have peculiar species. We shall mention only a few cases as examples of a general law.

Australia is undoubtedly the most striking case of all. The trees of this isolated continent are so different from those of the rest of the world that the whole aspect of field and forest is peculiar and strange. The animals are not only all different in species, but the genera and families and even many orders are peculiar. Of two hundred species of mammals, nearly all belong to a distinct subclass (non-placentals), including kangaroos, opossums, ornithorhynchus, etc., which, with the exception of a few species of opossums, are found only in Australia and the island appendages of that continent. *Madagascar* is separated by a deep sea from Africa, and we therefore find the organic forms entirely different from those of the neighboring continent, or of any other part of the world. It is especially characterized by the great number of lemurs. On the *Galapagos* (a small group of islands off the western coast of South America, but separated by a deep sea) the animals and plants are all peculiar. Reptiles of strange aspect abound, but no mammals (except, perhaps, one species of *mouse*) are known.

Thus we see that species are limited north and south by temperature, and in every direction by physical barriers. If, now, we add peculiar soil and climates (as in Utah, Arizona, etc.), which, of course, control vegetation and, therefore, animal life, it is easy to see that all these limiting causes produce groups of species confined within certain areas, and differing from other groups, sometimes overlapping and sometimes trenchantly separated.

Element of Time.—We have said that faunas and floras differ in proportion to the impassableness of the barriers between—i. e., the height and breadth of the mountain-chains, the extent of deserts, and the width and depth of seas, etc. But there is still another element of the greatest importance, viz., the *length of time elapsed since the barrier was set up.* This element of *time* connects *geographical faunas and floras* with *geological changes,* and thus geographical distribution of species becomes the key to the most recent of these changes. If we suppose species to undergo very slow changes, then the longer faunas are separated the greater becomes their difference. The full discussion of this important point requires a knowledge of the general laws of evolution, which we are not yet prepared to take up.

Primary Regions and Provinces.—Taking all the causes into account, the whole land-surface has been divided by Mr. Wallace into six faunal regions—viz. :

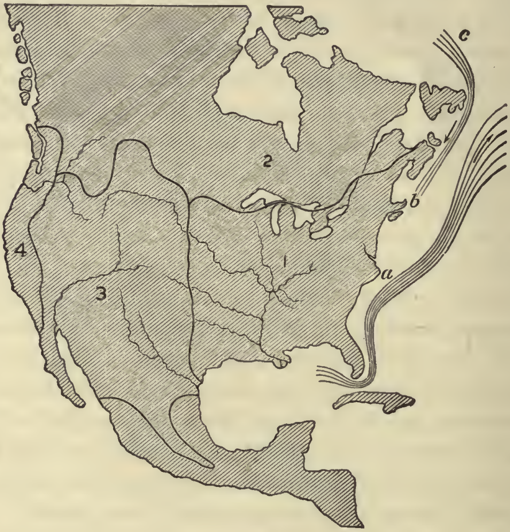

FIG. 69.

1. *Nearctic,* including all North America exclusive of Central America. 2. *Neotropic,* including Central and South America. 3. *Palæarctic,* including *Europe, Africa* north of the Sahara, and *Asia* north of the Himalayas. 4. *African,* including Africa south of the Sahara and Madagascar. 5. *Oriental,* including Asia south of the Himalayas and all the adjacent islands. 6. *Australian,* including Australia, New Zealand, New Guinea, and the South Sea Islands.

These primary regions are subdivided into provinces, and these into sub-provinces, according to the principles already explained. We will illustrate by only one example. The Nearctic region is divided into four provinces : 1.

Alleghanian; 2. *Canadian* or *boreal*; 3. *Rocky Mountain*; and, 4. *Californian*. The limits of these are shown in Fig. 69.

Marine Faunas.

Conditions are far less diverse in the sea than on land, and the limitation of fauna is less marked, but the same laws hold.

Temperature Regions in Latitude.—Fauna are here also arranged in zones determined by temperature. In a north and south coast-line, where the temperature changes gradually, the fauna will also change gradually by the substitution of one species for another; but if for any cause there is a more sudden change of oceanic temperature, there will be a correspondingly rapid change of fauna. For example, on our Atlantic coast, the Gulf Stream hugs the southern coast as far as Cape Hatteras (Fig. 69, *a*), and then turns away and runs at a greater distance. This makes a great change of temperature at this point. Again, the Arctic current, *c*, coming out of Baffin's Bay, hugs the coast of New England as far as Cape Cod, *b*, and then goes down. Thus Arctic conditions prevail in coast waters to this point. Thus there are three very different marine faunas along the coast of the United States—viz., a Southern, a Middle State, and a Northern; and these change somewhat suddenly at Capes Hatteras and Cod.

Distribution in Longitude.—By far the larger number of marine species inhabit along shore. For these the deep sea is a barrier no less impassable than the land. Therefore, the species inhabiting the two shores of an ocean like the Atlantic are as completely different as those inhabiting along the two coasts of a continent, as America.

Special Cases.—There are many species which live in the open sea and form a distinctive *Pelagic fauna*. Again, there are others which are conditioned by depth and character of bottom. The most remarkable of these are those inhabiting deep-sea bottom, and forming an abyssal fauna. Again, about the shores of isolated islands, as Madagascar and Australia, the marine fauna are as peculiar as the land fauna.

Origin of Geographical Diversity.

Until recently the most reasonable view seemed to be that species originated where we find them, and spread in all directions as far as they could. According to this view, the difference between faunas ought to be strictly in proportion to the impassableness of the barriers between. This is largely true, but does not account for all the phenomena. There is another element of equal importance, viz., *the time during which the barrier has existed.* It is probable that faunas and floras are subject to slow, progressive changes, taking different directions in different places. If there be no barriers, spreading by dispersal or migration prevents extreme diversity. But if a barrier be at any time set up by geological changes, then diversity commences, and *increases* with time. According to this view, the Australian fauna is so peculiar because this continent has been so long isolated from all others. The fauna of islands off the coasts of continents are often very similar to that of the adjacent mainland, because they have only recently been separated. Thus, for example, the fauna and flora of the British Isles differ but very slightly from those of the Continent, because, as we now know, these islands, even since their inhabitation by man, have been in full connection with Europe. The divergence has commenced, but is only varietal, not specific. This subject will be taken up again, and more fully explained in connection with glacial epoch, p. 403.

CHAPTER IV.

IGNEOUS AGENCIES.

ALL the agencies which we have thus far discussed tend to destroy the great inequalities of the earth-surface by cutting down the land and filling up the seas. They are therefore called *leveling* agencies. If they alone acted, they would eventually bring all to the sea-level and inaugurate a universal ocean. These agencies, however, are opposed by igneous or by *elevating* agencies, which, acting alone, would make the inequalities much greater than we now find them. The actual amount and distribution of land are the result of the state of balance between these two opposite forces. It is well to observe that the *leveling* forces are derived from the sun, while the elevating forces are derived from the *interior of the earth*—being in fact connected with interior heat. It becomes necessary, therefore, first of all to discuss this subject.

Interior Heat of the Earth.

The surface temperature of the earth varies with latitude, but the mean is about 60°. At any place the surface temperature varies between night and day (daily variation), and between summer and winter (annual variation). As we go below the surface, both the daily and the annual variation become less and less, and finally disappear. The daily variation disappears in a few feet, but the annual variation continues and disappears in our latitude only at a depth of sixty or more feet. Below this the temperature is *invariable.* The upper limit of the region of invariable temperature is called the *stratum of invariable temperature.* Its depth varies with latitude, being nearest the surface at the equator, and lying deeper as we go poleward.

As already said, below this stratum the temperature is invariable, but *it increases as we go deeper.* This important fact has been proved by observations in mines and artesian wells. It is true everywhere, but the rate of increase varies, being in some places more rapid (1° in thirty feet), in some less rapid (1° in ninety feet). The average may be taken, for convenience, at 1° for every fifty-three feet, or 100° for every mile of depth.

The Interior Condition of the Earth.—Now it is easy to see that at this rate the melting temperature for most rocks, say 3,000°, would be reached at a depth of about thirty miles. Hence, many persons have rashly concluded that the earth is essentially an incandescent, liquid mass, covered with a comparatively thin shell of thirty miles. This would correspond, in a ball of two feet diameter, to a shell of less than one tenth inch thick. On this view, volcanoes are supposed to be openings into this general interior liquid.

A little reflection, however, suffices to show that this condition of the interior is improbable. It is almost certain, in the first place, that the rate of increase is not uniform, but *decreases,* and therefore that the temperature of 3,000° would be found only at a much greater depth than thirty miles. In the second place, 3,000° is the fusing point under atmospheric pressure; but under the enormous pressure of thirty to fifty miles of rock, the fusing point would probably be much higher. Taking these two things into account, it seems *certain* that, if there be a universal interior liquid at all, the solid shell is much thicker than is usually supposed, and even *probable* that there is no universal interior liquid at all—and that volcanoes are openings into local reservoirs, not into a universal sea of liquid matter.

Recently there has been a tendency among geologists to accept a compromise between these extremes. It is now well known that rocks, under the combined influence of *heat and water,* fuse at a much lower temperature. This, to distinguish it from true dry fusion, is called *hydrothermal fusion.* While the temperature of true fusion is not less than 3,000°, that of hydrothermal fusion is only 600° to 800°. Now, water certainly penetrates the earth to great depths. Therefore many think that the general constitution of the earth is that of a solid nucleus and a solid crust, separated by a sub-crust layer of liquid or semi-liquid matter. There are many geological phenomena that are best explained by such a supposition.

The interior heat of the earth is the source of all igneous agencies. It shows itself on the surface in three principal forms, viz.: 1. *Volcanoes;* 2. *Earthquakes;* 3. *Gradual oscillations of the crust.*

SECTION I.—VOLCANOES.

Definition.—A volcano may be defined as a conical mountain, with a pit-shaped, cup-shaped, or funnel-shaped opening atop, from which are ejected, from time to time, materials of various kinds, always hot and often fused. They vary in size from inconspicuous mounds to mountains many thousand feet high.

Volcanoes may be *active* or *extinct.* Those which have not erupted for a century past are supposed to be extinct. Yet, so-called extinct volcanoes sometimes break out again. Until the great eruption which destroyed Herculaneum and Pompeii, Vesuvius was supposed to be an extinct cone. Since that time it has been very active. Again, in some rare cases, volcanic eruptions are constant. Stromboli and Kilauea, for example, are in feeble eruption all the time. But most volcanic eruptions are periodic. The period of intermission may be ten, or twenty, or fifty, or one hundred years.

Number, Size, and Distribution.—Humboldt enumerates 225 volcanoes as known to have erupted in the past century. The number now known is doubtless much greater. In *size* they vary from little mounds (monticles) to Mount Etna, 11,000 feet; Mauna Loa, 14,000 feet; and Aconcagua, 23,000 feet. In this last case the whole height is not due to volcanic eruptions, for the cone stands on a mountain plateau many thousand feet high; but the others are wholly built up by eruption. The *laws of distribution* may be briefly stated as follows: 1. Volcanoes are mostly on islands in the midst of the sea, or on the margins of continents bordering the sea. Only a very few have been found at a distance from the sea. The Pacific Ocean is the greatest theatre of volcanic activity. Its surface is dotted over with volcanic islands, and its margin is belted about with a fiery girdle of volcanic vents. 2. Volcanoes occur usually in lines, as if connected with a crust fissure, or else in groups, as if connected with a subterranean lake of fused matter. The most remarkable linear series of volcanoes is that which, commencing in the volcanoes of Fuegia, continues, as a chain of active vents, along the Andes and Mexican Cordilleras; then along the Sierra and Cascade, as the recently extinct volcanoes of these chains; then along the Aleutian Isles and Kamschatka; then through the Kurile Isles to Japan and the Philippines; then with more uncertainty to New Guinea, New Zealand, the Antarctic Continent, Deception Island, and back again to Fuegia, after completing the circle of the globe. The most remarkable groups are the Javanese group, the Hawaiian group, the Icelandic and the Mediterranean groups. 3. Volcanoes are found mostly in strata of comparatively recent date, and the retiring of the sea seems in many cases to be associated with their gradual extinction. The recently extinct volcanoes on the east side of the Sierra are good examples.

Phenomena of an Eruption.—In some cases, as in the Hawaiian volcanoes, the floor of the crater, hardened from previous eruption, becomes hot, then melts ; then the melted lava rises higher and higher, until it overflows and runs down the slope in one or more streams. The volcanic forces being thus relieved, the melted lava again sinks gradually to its former level, and hardens into a floor. Thus all proceeds with but little commotion. In other cases, as in the Javanese volcanoes, premonitions of coming violence are observed in the form of subterranean explosions attended with shakings of the earth ; then, with a powerful explosion, the floor of the crater is broken up, and the fragments are shot with violence, high, sometimes miles high, in the air ; then *cinders* and *ashes* and *smoke* are ejected in immense volumes ; then streams of lava are outpoured, perhaps alternating with explosions of *gas* and *vapor*, ejecting cinders and ashes. The ascending vapors are condensed, and fall as deluges of rain, which, with ejected ashes, form streams of *mud.* In all cases, if the mountain be snow-capped, the melting of the snow produces floods, which are often among the most disastrous features of the eruption.

Thus there are two extreme types of eruptions, the *quiet* and the *explosive.* In the one, the *ejecta* are mostly *lavas ;* in the other, gases, vapors, ashes, and cinders. The best type of the former are the Hawaiian, of the latter the Javanese volcanoes. But all grades between exist. The Icelandic volcanoes belong more nearly to the former type, the Mediterranean to the latter. Among Mediterranean, Etna approaches more the former, and Vesuvius the latter.

Quantity of Matter Ejected.—In the great eruption of Tomboro, in the Island of Sumbawa (one of the Javanese group), in 1815, the explosions are said to have been heard in Ceylon, nine hundred miles distant. The quantity of smoke and ashes was so great that, hanging in the air, they produced absolute darkness for many days, and falling, covered the sea over an area of one hundred miles radius. It has been estimated that the ashes ejected were sufficient to cover the whole of Germany two feet deep, and if piled in one place would make a mass three times the bulk of Mont Blanc (Herschel).

Of lava-eruptions, perhaps the greatest is that of Reykjanes (Skaptar) in 1783. The mass outpoured has been estimated as twenty-one cubic miles (Herschel). These, however, are extreme cases. One of the greatest eruptions of Kilauea, that of 1840, poured out a lava-stream forty miles long, which, if accumulated in one place, would cover an area of a square mile eight hundred feet deep. The average of lava-flows, however, is far less. One of the greatest eruptions of Vesuvius poured out 600,000,000 cubic feet of lava. This would cover a square mile twenty-two feet deep, or would make a stream seven miles long, one mile wide, and three feet thick.

Monticles.—In volcanoes of moderate height, eruptions usually come from the top of the cone or principal crater, but in very lofty volcanoes the pressure necessary to raise lava so high fissures the mountain in a radiating manner. These fissures are filled with liquid matter, which, on hardening, form radiating dikes. Eruptions often take place through these fissures, and thus form subordinate craters and cones about the main cone; these are called *monticles.* About six hundred such monticles dot the surface of Mount Etna, some of which are seven hundred feet high above the level of the mountain-slope on which they stand. About Mount Shasta (which is a recently extinct volcano) are found a number of these monticles.

Nature of the Materials Erupted.—The materials erupted are—1. Rock-fragments. 2. Lava. 3. Cinders. 4. Sand. 5. Ashes. 6. Smoke. 7. Gas. The rock-fragments are formed in explosive eruptions by the breaking up of the hardened floor of the crater, and require no further explanation.

Lava.—This term is applied to melted rock, or to the same after it has hardened again. The degree of liquidity depends partly on the degree of heat and partly on the *kind of fusion.* The lava of Kilauea is as liquid as honey. The bursting of bubbles on the surface of this thin, viscous liquid draws it out into hair-like threads like spun-glass, which is borne by the winds and accumulated in certain parts of the crater. This is called *"Pele's hair."* Thin lava like this, when it first issues from the crater, runs with great velocity, twenty to twenty-five miles an hour; but as it cools it becomes stiffer, first like tar, then

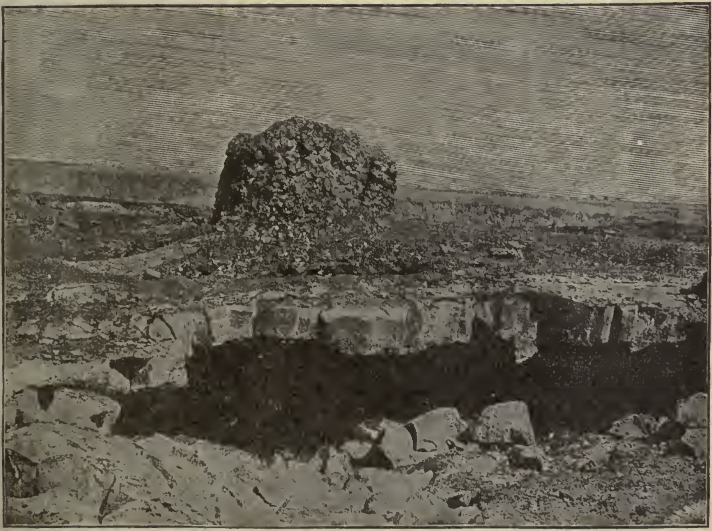

Fig. 70.—Lava-tunnel, and "spatter-cone" formed by escaping steam, Kilauea. (Photograph by Libbey.)

like pitch, and therefore runs with less and less speed, until it becomes rigid and stops. Being a bad conductor of heat, lava cools and forms a crust on the surface while it is still liquid and flowing within. The liquid finally flowing out, often leaves a hollow tube or *gallery*. Again, since all lava contains more or less of gas and vapor, the crust is a sort of concreted lava-foam. This vesicular, spongy lava is called *scoria*. Sometimes, in very stiffly viscous lava, the vapor-bubbles run together and form huge blisters, which, by hardening, form *caves*. Thus, nearly all lava-beds are full of galleries and caves. It was in the galleries and caves which honey-combed the ancient lava-flows of southern Oregon that a handful of Modocs defied so long the power of the United States Army.

Again, the liquidity of lava, and its appearance after solidifying, depend much upon the *kind* of fusion. Lavas are often in a state of *hydrothermal* fusion (page 133), i. e., half fusion, half solution in superheated water. Such a semi-fused mass, on concreting, makes a kind of earthy stone. Sometimes, in fact, the *ejecta* are little more than hot mud, and concrete into *tufa*.

Cinders, Sand, and Ashes are only different forms of hardened lava. The liquid lava, before ejection, may be so largely mingled with gas and vapors that it is literally a *rock-foam*. Masses of this rock-foam, ejected with violence into the air, cool and fall as cinders. Often the greater part of the ejections is of this kind, and thus are formed cinder-cones. Sometimes the violence of the explosions is so great as to break up the liquid mass into *rock-spray*. This falls again as *sand* or *ashes*, according to its fineness ; or else the rock-fragments and cinders are thrown up, and, falling again repeatedly, may be triturated into dust or ashes. The finest rock-dust hanging in the air is called *smoke ;* the same, fallen to the earth, *ashes*. Volcanic ashes, wet with water and consolidated either on the spot or after transportation and sorting, is called *tufa*.

Physical Conditions of Lava.—If lava cools very slowly, the minerals of which it is composed separate and crystallize more or less perfectly. This is *stony lava*. If it cools rapidly, it forms *volcanic glass*. If the volcanic glass be full of vapor-bubbles, it forms *scoria*. If volcanic ashes mixed with water solidifies, it makes *tufa*. Thus there are four physical states in which we find lava, viz., *stony, glassy, scoriaceous*, and *tufaceous*.

Classification of Hardened Lavas.—Hardened lava consists essentially of two principal minerals, viz., feldspar and augite.* If the former predominate, it is called feldspathic ; if the latter, augitic lava. These two minerals are often not detectable except with the microscope, and yet the two kinds of lavas may usually be distinguished by the eye. The lighter colored and lighter weighted are usually feldspathic ; the darker and heavier, augitic. The feldspathic lavas are said to be *acidic ;* the augitic, *basic*. Both of these kinds take on the four physical states mentioned above. Feldspathic lava, in the stony condition, is *trachyte ;* in glassy condition, *obsidian ;* in scoriaceous condition, *pumice ;* in tufaceous, the *light-colored tufas*. Augitic lava, if stony, is *basalt ;* if glassy, *pitchstone ;* if scoriaceous and tufaceous, *black scoriæ* and *tufas*.

Gases and Vapors.—The gases ejected from volcanoes are steam, chlorhydric acid, sulphurous acid, sulphhydric acid, and carbonic acid (H_2O, HCl, SO_2, H_2S, CO_2). The first three are characteristic of true eruptions, the others of feeble, secondary volcanic activity. Of all, steam is by far the most abundant. In volcanoes of the explosive type the quantity of steam is often enormous. This fact strongly suggests this vapor as the main agent of eruption. *Flames* are often spoken of in eruptions. It is possible that there may be sometimes feeble flame from the combustion of H or H_2S, but probably the so-called flame is nothing else than the ruddy reflection of the glowing liquid in the crater upon the smoke and cloud hanging in the air.

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* The pupil ought to be shown specimens of these minerals.

Formation of Volcanoes and their Structure.—It is now generally admitted that volcanic cones are built up mainly by their own eruptions. On this view, their origin and mode of growth may be briefly described as follows: 1. The increase of heat (by causes which we little understand) at the focus of the volcano thins the crust in that point, until it gives way, and the melted matter is outpoured on the surface around the opening. 2. With every eruption the accumulated material rises higher and spreads farther; and thus a conical mound is formed. The shape of this mound will depend on the kind of matter erupted. If it be very liquid lava, it will spread far, and the cone will be low in proportion to the base, as in the Hawaiian volcanoes (Fig. 71); but if the material be cinders, these will pile up into a steep cone (Fig. 72). The repeated layers of lava or cinders produce a stratified appearance; but this must not be confounded with true stratification. 3. With every eruption, the eruptive throes split the sides of the cone with radiating cracks, which, filling with liquid and hardening, form radiating rocky ribs called *dikes* (Fig. 73), and these bind the lava or cinder

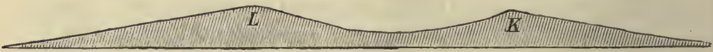

Fig. 71.—Section across Hawaii. *L*, Mauna Loa; *K*, Mauna Kea.

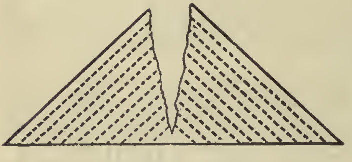

Fig. 72.—Section of cinder cone.

layers into a stronger mass. 4. When the cone grows very high, eruptions will take place through these fissures, as well as from the top crater, and thus will be formed secondary cones or monticles. 5. If any of these monticles cease to erupt, they will be covered up by ejections from the main crater or other secondary craters. All these facts are shown in Fig. 74. 6. From time to

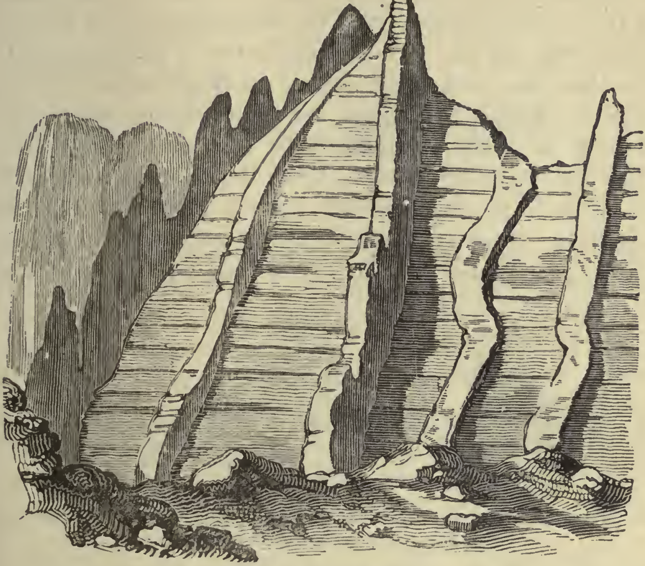

FIG. 73.—Dikes in Etna.

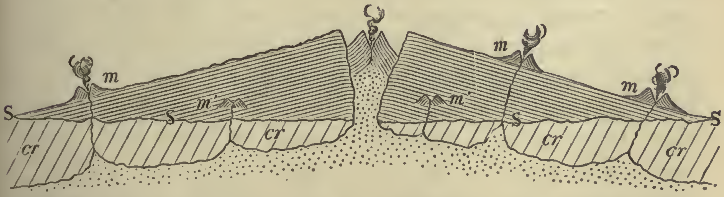

FIG. 74.—Ideal section of a volcano. *ss*, original surface; *mm*, monticles; *m′m′*, extinct monticles; *cr*, *cr*, original stratified crust.

time, at very long intervals, there occur very great eruptions. If the volcano be of the quiet type, the whole top of the cone is melted, and, after eruption, is ingulfed; or if of the explosive type, the whole top of the cone is blown into the air, and the mountain is disemboweled. In either case a yawning chasm many miles in extent is left. 7. Within this great crater, by subsequent eruptions, is built up a smaller cone, and within this again often still smaller cones. Thus volcanoes often have about their present eruptive cone a great surrounding *rampart*. This rampart is the remains of the great crater. In Vesuvius (Fig. 75), Mount Somma, *s*, is the remains of such a great crater, the other side of it being broken down, and now covered by flows from the present crater.

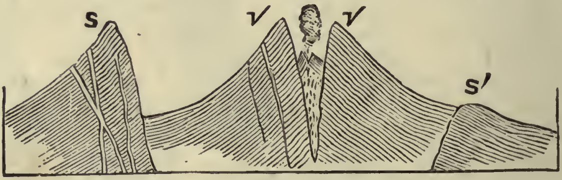

FIG. 75.—Section of Vesuvius. *vv*, Vesuvius cone; *s*, Mount Somma; *s'*, other side of Somma overflowed by lava from Vesuvius.

Crater Lake.—An excellent example of this structure is found in Crater Lake. This beautiful lake, with its splendid blue waters, occupies a yawning chasm on the top of an extinct volcano in southern Oregon. The lake itself is about six miles in diameter and 2,000 feet deep (the deepest lake on the American continent), and is surrounded by almost perpendicular walls, 1,000 to 2,200 feet high. From the midst of the blue waters, but nearer one side, there rises a beautiful island (Wizard Isle), 800 feet high, which is in fact a cinder cone with a small crater atop. Fig. 76 gives an ideal section of the lake and island, and also, in dotted outline, the supposed form and height of the original volcano before ingulfment. This former volcano has been named Mt. Mazama.

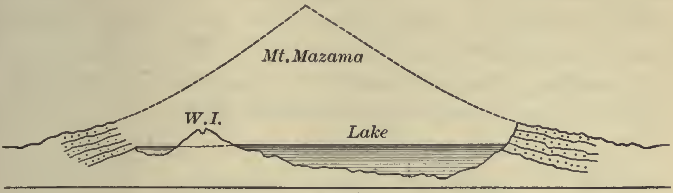

FIG. 76.—Ideal section of Crater Lake, Mt. Mazama, and Wizard Isle. (After Diller.)

Age of Volcanoes.—From the progressive manner in which volcanoes grow, it would seem that we may estimate their age. Such estimates, it is true, must be very rough, yet they are useful in familiarizing the mind with the idea of the great amount of time necessary to account for geological phenomena. For this purpose we will use Etna. There have been, indeed, other volcanic eruptions great enough to build this mountain at once, but the eruptions of Etna itself have been very regular and moderate.

Etna is 11,000 feet high, and about thirty miles in diameter at its base. We will take its circumference at one hundred miles. Now, a lava-stream of triangular shape, one foot thick, reaching to the base, and one mile wide, would, we believe, be an average eruption. It would cover seven square miles, one foot deep, and would be equal to more than 200,000,000 cubic feet. It would take one hundred such eruptions to raise the whole mountain-surface one foot. Taking one such eruption every year (eruptions of Etna for the last 2,000 years have been but one in twenty-five years), it would take a century to raise the mountain-surface one foot. But there is a gorge cut into the side of this mountain, revealing 3,000 feet of lava-layers. To have built up these 3,000 feet would require 300,000 years. That we have been moderate in our estimate is shown by the fact that there are known on the flanks of Etna lava-flows 2,000 years old, which are still not covered by subsequent flows. We are justified, then, in saying that Etna is probably much more than 300,000 years old. But the birth of Etna is a very recent geological event, for it stands, and has been built up, on the latest tertiary formation.

Cause of Volcanic Eruptions.

This question is still very obscure. There are two things to be explained, viz., volcanic *force* and volcanic *heat*—the force necessary to raise lava to the lip of the crater, and the heat necessary to melt the lava.

(*a.*) *Force.*—If we consider the height of volcanic cones, we shall be better able to appreciate the greatness of the force. In the accompanying table we give the heights of some well-known volcanoes and the pressure in atmospheres (one atmosphere = fifteen pounds per square inch, or one ton per square foot) necessary to raise lava (taking the specific gravity at 2.8) to the lip of the crater. It is true lava is sometimes foamy, and therefore lighter, but, on the other hand, we have taken the focus of volcanoes at sea-level, while it is probably much deeper, and have supposed the force only sufficient to raise to the lip of the crater, whereas it often ejects with violence many thousand feet in the air.

NAME.	Height.	Pressure in atmospheres.
Vesuvius	3,900 feet	325
Etna	11,000 "	920
Mauna Loa	13,800 "	1,150
Cotopaxi	19,660 "	1,638

What, then, is the agent of this great force? It is believed that it is the elastic force of compressed gases and vapors, especially *steam*. The power of these agents is well known; and gas and steam issue in immense quantities during eruptions, especially of the explosive type. On this point there is little difference of opinion.

(*b*.) *Heat*.—But the cause of the heat necessary to fuse the rocks is one of the most difficult of all questions connected with the physics of the earth. By most geologists it is thought to be connected with the primal heat of the earth, and the supposed universal melted condition of the interior. This view assumes (*a*) that the earth was once an incandescent, fused mass. This is almost certainly true; (*b*) that in cooling it formed a crust, which thickened by additions to its inner face, until it is now about thirty miles thick; (*c*) and that this limit between the solid crust and melted interior is the place of the focus of volcanoes. There are many difficulties in the way of acceptance of this view, some of which are given on page 132.

All other theories regard the melted matter as *local*, but, as to the cause of the fusion, there is yet great diversity of view. Some attribute it to chemical action; some to mechanical crushing. It must be remembered in this connection, however, that in some cases, at least, the amount of heat required is not more than 800° F., for in some lavas the fusion is *hydrothermal*, and in all cases the access of water seems necessary to supply the force.

Secondary Volcanic Phenomena.

There are many phenomena which linger after the true eruptions have ceased. The chief of these are *hot* springs, *carbonated* springs, *lime-depositing* springs, *solfataras*, *fumaroles*, *mud-volcanoes*, and *geysers*. These all seem to be the result of circulation of water through lavas which still retain their heat, and are therefore properly called secondary volcanic phenomena. The lavas, outpoured by primary or true eruptions, remain hot in their interior for an indefinite time. If waters, percolating through these, come up again after taking up *only heat,* they form hot springs. If, in addition, they take up CO_2, they form carbonated springs. If lime be taken and deposited on the surface, they form lime-depositing springs (p. 73). If the heat be great, so that vapors are given off and condensed as clouds, they are called fumaroles. If the waters contain H_2S, and AlkS, they are called solfataras. If mud is brought up and deposited about the vent, they are mud-volcanoes. Finally, if the springs are periodically and violently eruptive, they are called *geysers.* The only variety of these springs which need detain us here is

GEYSERS.

Geysers may be defined as periodically eruptive springs. They seem also usually, if not always, to deposit silica. They are found only in Iceland, in New Zealand, and in Yellowstone Park. The so-called California geysers are solfataric fumaroles. Steamboat Springs in Nevada may possibly be classed with geysers, but their eruptions are feeble. The phenomena of true geysers are so splendid that a somewhat full account of them is necessary. As they were first studied in Iceland, and the cause of their eruption was first understood there, we will speak of these first.

Geysers of Iceland.—Iceland may be briefly described as a plateau 2,000 feet high, studded with volcanic peaks, with margin sloping gently to the sea. Only the marginal area is to any extent inhabited. The interior is a scene of desolation, where every form of volcanic phenomena exists in the greatest activity—volcanoes, hot springs, boiling springs, fumaroles, solfataras, and geysers. Of these last there are very many in various degrees of activity. The most celebrated of these is the *Great Geyser.*

Great Geyser.—This is a low mound, with a basin-shaped depression at top, from the bottom of which descends a tube or well to unknown depth, but may be sounded to eighty feet or more. The basin is fifty feet across, and the tube or throat ten feet in diameter at the top but narrowing downward. Both the basin and the throat are lined with silica deposited from the water, and doubtless the mound itself was built up by similar deposits. In the intervals between eruptions the basin is filled to near the brim with water at 180°.

Phenomena of an Eruption.—As the time for the eruption approaches, the first thing observed is a series of explosions in the bottom of the throat like subterranean cannonading; then bubbles of vapor are seen to rise and burst on the surface; then the water of the surface bulges up and overflows. Immediately thereafter the whole of the water in the throat and basin is ejected with violence one hundred feet into the air, forming a fountain of dazzling splendor, followed by the roaring escape of steam. As the water falls back, it is again ejected, and the fountain continues to play several minutes until the steam has all escaped and the water partly cooled; then all is quiet again until another eruption. The interval between eruptions is irregular. An eruption may be brought on prematurely by throwing large stones down the throat of the geyser.

Yellowstone Geysers.—But in splendor of eruption the Icelandic geysers are far surpassed by those of Yellowstone Park. This, like Iceland, is a volcanic region, but, unlike Iceland, primary volcanic phenomena are all extinct. The geyser phenomena here occur in a narrow valley surrounded on all sides with volcanic rocks of great thickness, of comparatively recent origin, and doubtless, therefore, still hot in their interior. In this little valley there are no less than 10,000 vents of all kinds, hot springs, boiling springs, mud-volcanoes, lime-depositing springs, and geysers. On Gardiner's River the vents are mostly hot carbonated springs, depositing lime; on Firehole River they are geysers, depositing silica. In Yellowstone Park alone there are in all 3,000 vents, of which sixty-two are eruptive geysers. In the lime carbonate springs the deposits on hillsides have given rise to a succession of terraces (Fig. 41, page 75), and sometimes the water descending through a succession of pools from terrace to terrace gives rise to beautiful stalactitic forms (Fig. 77). In the geysers the hot alkaline waters collect in pools, and deposit the silica first in a gelatinous condition, which afterward concretes into all kinds of fantastic forms (Fig. 78). The deposit immediately about the eruptive

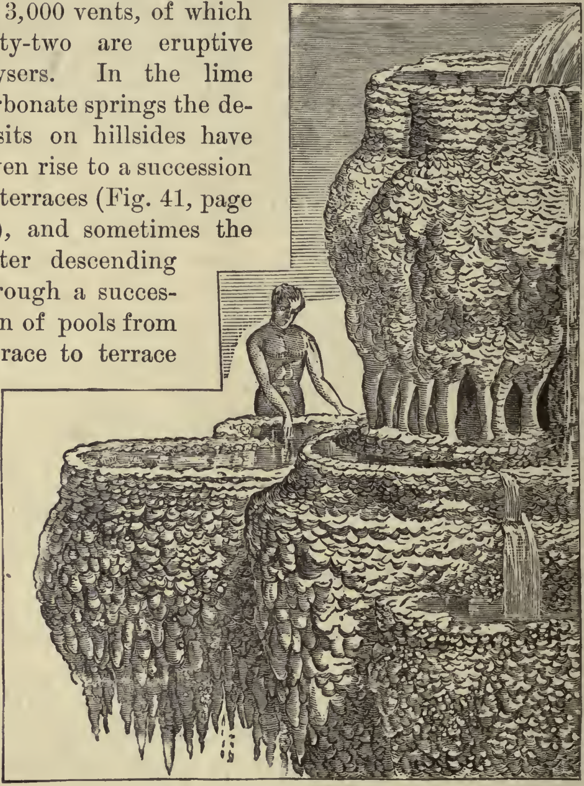

Fig. 77.—Deposits from carbonated springs.

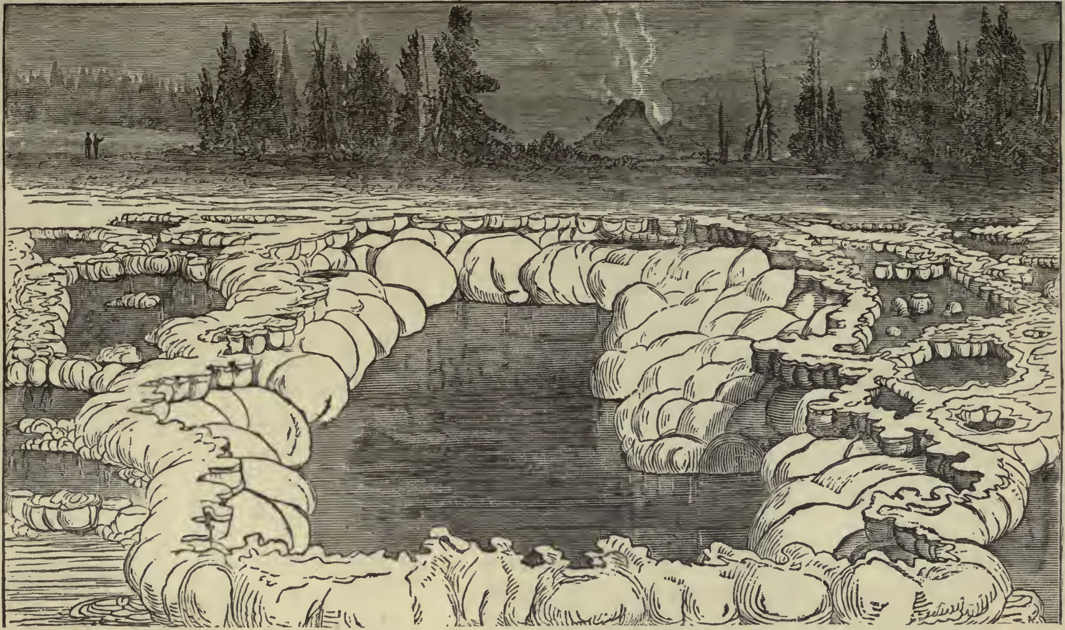

FIG. 78.—Geyser near the Giant, showing the ornamental character of the border. (After Hayden.)

vents builds up moundlike, hivelike, and chimneylike forms (Fig. 79). The silica-charged waters, trickling slowly over the mounds, give rise by deposit to patterns of exquisite and delicate beauty, compared by Hayden to embroidered lace-work with edging-fringe and pendent tassels, and studded with pearls. Similar deposits are formed also in New Zealand; we give an example in Fig. 80. Only a few of the grandest of these geysers can be mentioned:

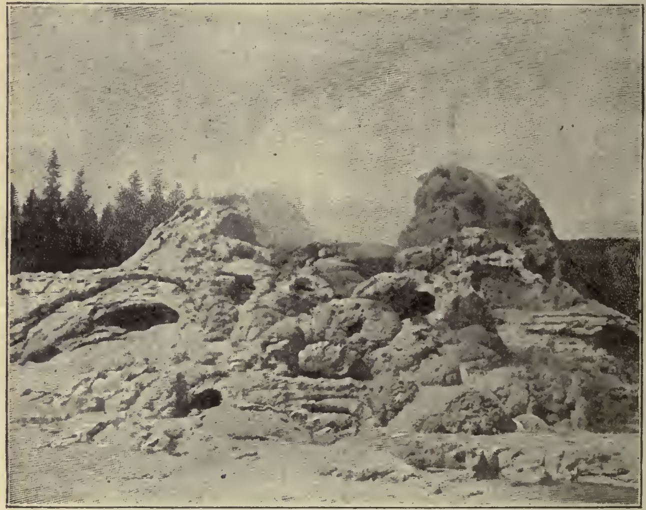

FIG. 79.—Crater of Castle Geyser, Yellowstone Park.

1. The Grand Geyser throws up a column of water six feet in diameter to the height of 200 feet, while the steam ascends 1,000 feet or more. The eruption is repeated every thirty-two hours, and lasts twenty minutes.

2. The Giant (Fig. 81) throws a column five feet in diameter 140 feet in the air, and plays continuously for three hours.

3. The Giantess, the greatest of all, throws up a huge

column twenty feet in diameter to the height of sixty feet, and through this great mass it shoots up several lesser jets to the height of 250 feet. It erupts about once in eleven hours, and plays twenty minutes.

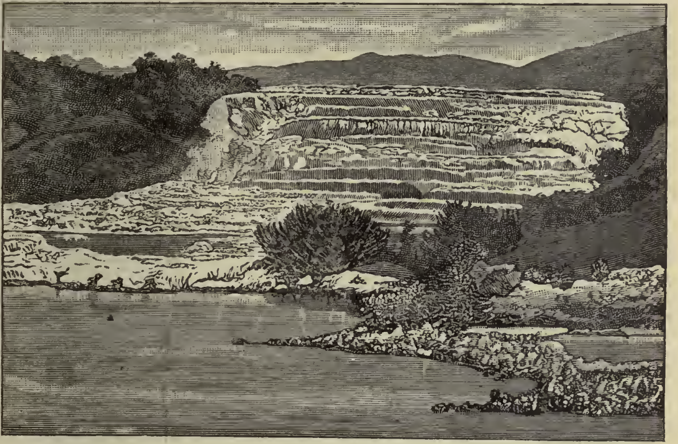

FIG. 80.—Pink terraces, New Zealand. (After Peale.)

4. The Beehive, so called from the shape of its mound, shoots up a splendid column two to three feet in diameter to the height of 219 feet, and plays fifteen minutes (Fig. 82).

5. Old Faithful, so called from the frequency and regularity of its eruptions, throws up a column six feet in diameter to the height of 100 to 150 feet, and plays fifteen minutes (Fig. 83).

Cause of Geyser Eruption.*—This may be explained, in a very general way, as follows: Experiments show that the heat of the water rapidly increases as we pass down the geyser-throat. There is no doubt, therefore, that in spite of the increasing pressure (which raises the boiling-point)

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* For a complete discussion of this interesting subject, see author's "Elements," pp. 99–104.

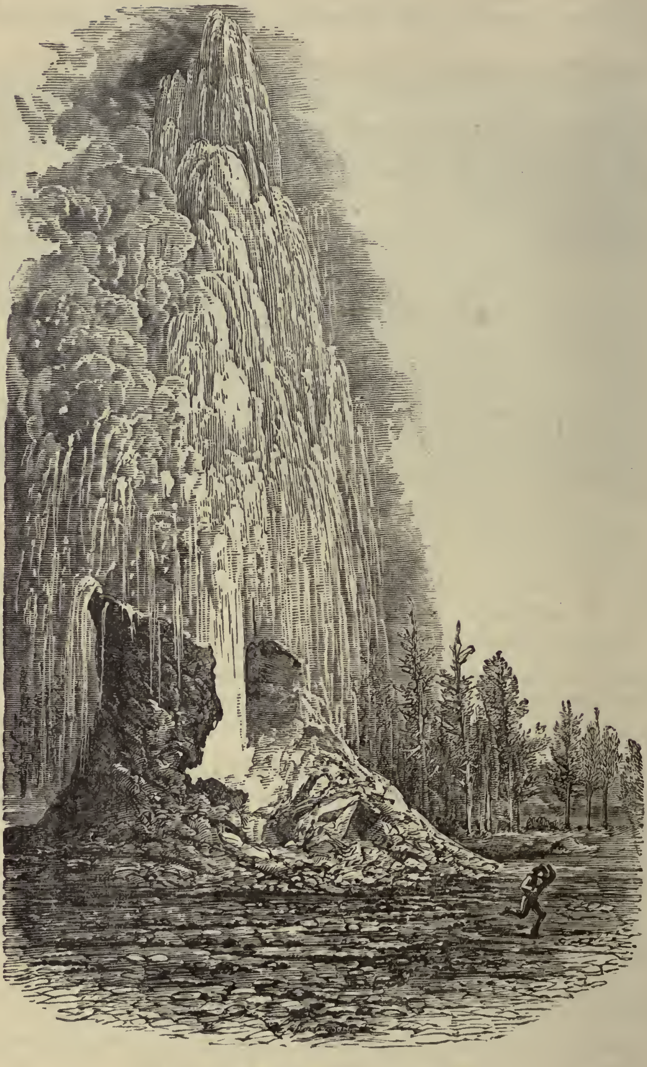

FIG. 81.—Giant geyser. (After Hayden.)

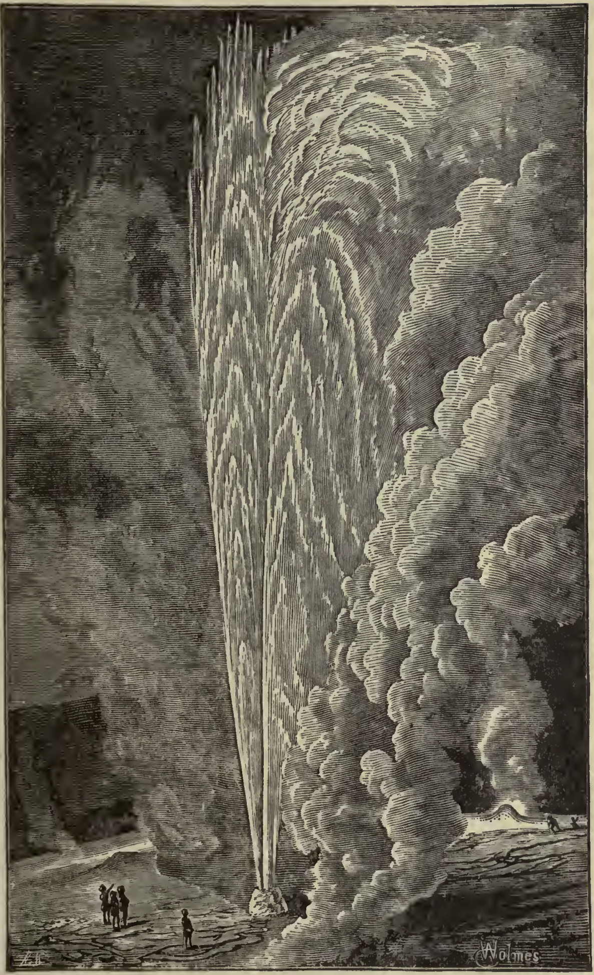

FIG. 82.—Beehive geyser. (From a drawing by Holmes.)

the boiling-point is reached and a large quantity of steam is formed first, at some point deep below. The water above is immediately ejected, and the fountain continues to play until all the steam escapes and the water is somewhat cooled. Then all is quiet until the water again heats up to the boiling-point.

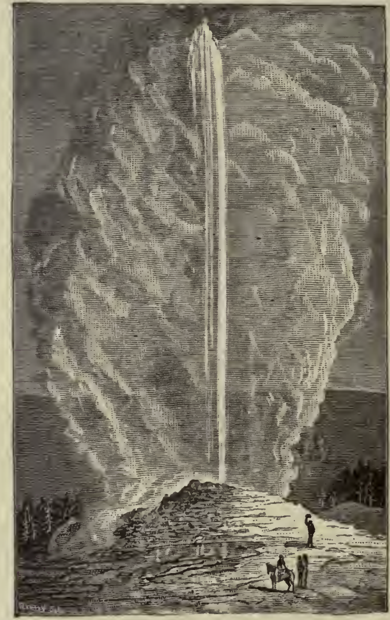

Fig. 83.—Old Faithful geyser in action. (After Hayden.)

SECTION II.—EARTHQUAKES.

When we consider the suddenness with which earthquakes occur, the terror they inspire, and the place of their origin, deep in the interior of the earth, and hidden from observation, it is not surprising that we know so little about their cause. In fact, until about forty years ago no attempt had been made to study them scientifically. Now, however, it is believed the foundations of a true science of earthquakes (seismology) have been laid, and a true progress has been made. The basis has been laid by Mr. Mallet, and progress has been made possible by the use of self-registering seismometers.

Frequency of Earthquakes.—The slow development of earthquake-science is not due to want of material, but, as has already been stated, partly to the difficulty of the subject, and partly to the terror produced—unfitting the mind for scientific observation. The earthquake catalogue of Alexis Perrey records 18,000 in thirty years (1843–1873), or nearly two a day. When we remember that three-fourths of the earth's surface is covered with the sea, that a large portion of the land-surface is inhabited by uncivilized races, and that even in civilized countries many slight tremors are unrecorded, it will not seem extravagant to say that, probably, there is not an hour of any day in which the earth is not shaking in some portion of its surface.

Phenomena of an Earthquake.—In brief, the phenomena of an earthquake are: 1. *Sounds,* sometimes like underground *cannonading;* sometimes a hollow *rumbling,* or *clashing,* or *grinding.* 2. Accompanying, or immediately succeeding, comes the movement of the earth, as a slight tremor, or as a violent shaking; in extreme cases, so violent that the houses of whole cities are shaken down, like card-houses of children, and bodies on the surface are thrown up a hundred feet into the air, as at Riobamba in 1797. 3. As to *direction,* the movement may be *up and down,* or from *side to side,* or partaking of both, i. e., *obliquely,* or it may be rotating or *twisting,* as, for example, when chimney-tops are twisted about without being upset, or wardrobes and bureaus turned about before upsetting. 4. One thing is always observed and is of primary importance, viz., that the shake does not occur everywhere at the same time, but on the contrary appears first at one place and spreads thence in all directions, precisely like a system of waves when a stone is thrown into the water. This point of first appearance is called the "*epicentrum*," because it is immediately *above the origin*. The violence of the earthquake is greatest there, and thence decreases precisely like a system of widening circular waves.

Velocity of Shock and of Transit.—The velocity of the spread from the center or velocity of travel (transit) must be carefully distinguished from the velocity of the earth-movement (shock). There is no close relation between these. We may best illustrate this by water-waves. Suppose we are in a boat on the surface of a bay traversed by long, low swells. As each swell passes under us, we are *slowly* heaved up and slowly let down again, but the waves are here, there, and away with great velocity. The velocity of oscillation is small, the velocity of transit is great. But if the surface of the bay be agitated by short, high waves, the oscillation or shaking is more rapid, but the transit is comparatively slow. So in earthquakes, the movement may be only a slow heaving up and down, or swinging back and forth, and yet this movement may travel from place to place with great velocity. Now, as in water-waves generated by a stone thrown in still water, so in earthquakes, the velocity and amount of movement (which is equivalent to the wave-height) is greatest at the center (epicentrum), and diminishes as it spreads, but the velocity of the transit or travel is nearly or quite uniform.

Now, the velocity of transit has been determined in many earthquakes by noting the time of arrival at different places. It varies with the kind of rock, being greatest in the hardest, and also with the depth of the origin, being greater for very deep earthquakes. In some cases it is only ten miles per minute; sometimes fifteen, twenty, thirty miles per minute, or even much more. Sometimes the spread is equally rapid in all directions, and the spreading wave is *circular,* or nearly so; sometimes it is more rapid in one direction than another, and the spreading wave is *elliptical.*

Cause of Earthquakes.—The origin of earthquakes being deep beneath the surface and hidden from observation, their cause is very obscure. Yet their association with other forms of igneous agency suggests *probable* causes:

1. Volcanic eruptions, especially of the explosive type, are always accompanied by slight and sometimes by serious earthquakes. This fact suggests the sudden formation of gases or the sudden collapse of vapors as a possible *cause.* On this view an earthquake would be like the earth-jar produced by a mine-explosion, or by the explosion of large quantities of gunpowder or nitro-glycerine.

2. But great earthquakes are oftener associated with bodily movements of extensive areas of the earth-crust. Thus, for example, in 1835, after a severe earthquake on the western coast of South America, it was found that the whole coast-line of Chili and Patagonia was raised from two to ten feet above sea-level. Again, in 1822, the same phenomenon was observed in the same region after a great earthquake. Again, in 1819, after a severe earthquake which shook the delta of the Indus, a tract of land fifty miles long and sixteen miles wide was raised ten feet, and an adjacent area of 2,000 square miles was sunk, and became a lagoon. In commemoration of the wonderful event, the elevated tract was called *Ullah bund,* or, the mound of God. Again, in 1811, a severe earthquake—perhaps the severest (except the Charleston earthquake of August, 1886) ever felt in the United States—shook the valley of the Mississippi. Coincidently with the shock, large areas of the river-swamp sank bodily, and have ever since been covered with water. In commemoration of the

event, this area is still called the *sunken country*. In all these cases, probably, and in the last two certainly, there was a great *fissure* of the earth-crust, and a *slipping* of one side on the other.

Now, these facts suggest another and, we believe, a more probable cause of earthquakes. It is well known that there are operating within the earth forces elevating or depressing or crushing together portions of the crust. We will discuss the nature of these forces in Part II. Suffice it to say now that it is in this way that continents are elevated and mountain-ranges are formed. Now, suppose such forces operating to raise or depress large areas of the crust—e. g., the southern end of South America—it is evident that, the interior forces lifting and the stiff crust resisting, there would come a time when the crust would break—i. e., form a great fissure. Such a sudden break would produce an earth-jar which would propagate itself from the fissure as focus in all directions as an earthquake. Or, again, after such a fissure is formed, the two walls may at any time *slip* on each other and produce an earth-jar. Now, this is not mere speculation. We find such great fissures intersecting the earth in many places; they break through miles of thickness of rock, and in many cases the two walls are slipped on each other several thousand feet vertically. It is almost certain that *earthquakes are produced by the formation or the slipping of such fissures.* In 1873 there was a severe earthquake in Inyo County, California, just at the eastern base of the Sierra. Now, there is on that side of the range a great fissure and a slip of several thousand feet. It is almost certain that the earthquake was produced by a slight readjustment of the position of the walls of this fissure. Moreover, the thorough investigations very recently of several earthquakes have seemed to establish the fact that they originated in the formation or the readjustment of a fissure.

Nature of Earthquake-Waves.—In any case, it is evident that an earthquake is produced by concussion of some kind somewhere in the interior of the earth, usually at a depth of from six to ten miles. The concussion gives rise to a series of elastic earth-waves, spreading in all directions *spherically,* like sound-waves, until they reach the surface, and then spread in all directions on the surface as a *circular* wave, as in Fig. 84. The interior point of origin (x) is called the *focus,* or centrum; the point of first emergence (a), the epicentrum. It is the passage of a series of these circular waves beneath the feet of the observer at any point (d) that gives rise to the actual observed phenomena; so that the scientific discussion of earthquake phenomena is little else than the discussion of such earth-waves emerging and spreading on the surface.

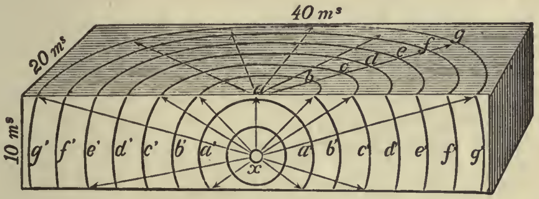

FIG. 84.—Section and perspective of a portion of the earth's crust shaken by an earthquake, showing origin, x; section of the spherical waves, a', b', c', etc., and perspective of the outcropping surface waves, a, b, c, etc.

Earthquakes occurring beneath the Sea.—We have thus far spoken of earthquakes occurring beneath the land; but three fourths of the earth-crust is covered with water, and therefore it is probable that the larger number of earthquakes have their origin beneath the sea-bed. Besides, as we shall see hereafter in treating of mountain-chains, marginal sea-bottoms are particularly liable to movements. When an earthquake occurs beneath the sea-bed, there are some additional phenomena, which must now be discussed.

Suppose, then, a concussion, from any cause, beneath the sea-bed. There would be formed, as before, about the focus, a series of spherical earth-waves, which, by enlargement, would emerge on the surface of the sea-bed as circular surface-waves. These, spreading beneath the sea, would reach the nearest shore, and produce their destructive effects there. Some time afterward, perhaps a half-hour or more, there comes rolling in on shore a prodigious water wave, or perhaps a series of water waves, thirty to sixty feet high, deluging the whole shore region, and completing the destruction commenced by the earth-wave.

The Great Sea Wave.—This very destructive accompaniment of earthquakes occurring beneath offshore sea-beds may be explained as follows: The bed of the sea at the epicentrum is lifted up perhaps several times. This lifts the whole sea water above, so that the surface is raised into a water mound. This mound immediately sinks as much below the sea level as it was before raised above it, and thus gives origin to a circular water wave (or series of such waves) which spreads exactly like any other water wave, growing lower as its spreads, until it breaks on the nearest shore. Out at sea such great low waves would pass under a ship unobserved, heaving it slowly up and letting it down again. But when they approach shore, on account of their great size, often fifty feet high and one hundred to two hundred miles across the base, they rush forward as a tide fifty feet high and devastate the whole coast within their reach. They are, therefore, sometimes called *tidal* waves, although they have nothing to do with tides. Though originating at the same place, the great sea wave moves much less rapidly than the earth-wave, and therefore reaches the shore later.

Examples of the Great Sea Wave.—1. In 1755 a terrible earthquake destroyed Lisbon, and, it is said, forty thousand people. The focus of this earthquake was beneath the sea-bed, perhaps one hundred miles off shore. The arrival of the earth-wave shook down the houses. Then, after a half-hour, when all was quiet, there came great sea waves sixty feet high and completed the destruction of the city. These waves were sixty feet high at Lisbon, thirty feet at Cadiz, eighteen feet at Madeira, and five feet on the coast of Ireland. They were also felt on the coast of Norway and on the West India Islands, after having traversed the breadth of the Atlantic.

2. In 1854 an earthquake shook the coast of Japan. A half-hour afterward a great wave, thirty feet high, came in and swept the town of Simoda clean away. The epicentrum was probably a hundred miles off shore. The wave, spreading in all directions, was highest on the coast of Japan, because this was near the epicentrum. But in the other direction it was observed at the Bonin Islands fifteen feet high, and—after traversing the Pacific and being nearly exhausted—on the California coast, only eight inches high at San Francisco and six inches at San Diego.

3. In August, 1868, a very destructive earthquake shook the coast of Peru, severest about Arica. The epicentrum was not far off shore, for in five minutes afterward there came in great sea waves sixty feet high and desolated the whole coast, carrying ships far inland and stranding them high up on the mountain slopes. These great waves were traced southward to Coquimbo and beyond, northward to San Francisco, Astoria, and Sitka, southwestward to Australia and New Zealand, and westward to Hawaii and Japan, thus having traversed the whole breadth of the Pacific. Were it not for the obstructing continents, there is no doubt that they would have encompassed the earth in their widening circles.

In regard to these waves, there are several points worthy of notice :

a. Their *velocity,* though less than that of earth-waves, is enormously great for water waves. The wave of 1854 traversed the Pacific, from Japan to San Francisco, a distance of 4,500 miles, in about twelve hours, or at a rate of 370 miles an hour. The wave of 1868 ran across the Pacific with even greater speed. The reason of their great velocity is their enormous size.

b. The *size* of the great sea wave is determined by the principle that *every wave runs its own length in the time of one oscillation.* If a boat be lying on smooth water, and a series of water waves passes under it, the boat will be moved up and down *once* while the waves run the length of one wave; i. e., from trough to trough. Now, the time of oscillation of the great sea waves of 1854 was about thirty-three minutes. If, then, the waves run 370 miles in an hour (60 minutes), how much did they run in 33 minutes—60 : 33 : : 370 : 203. Therefore, these waves were 203 miles from trough to trough.

c. The mean depth of the ocean may be determined by these waves. The principle on which this is done is as follows: Every one has observed that waves coming in from deep water on to a flat, shelving shore, at a certain depth begin to drag bottom, and are impeded thereby; also, that the larger the wave, the deeper the water in which it begins to drag. Now, in the case of these enormous earthquake sea waves, the ocean itself is not deep enough to prevent them from dragging bottom. As they run over the sea their velocity is impeded everywhere, but more or less according to the varying depth of the ocean. Now, the normal or unimpeded velocity of a wave may be accurately calculated, since it varies as the square root of the wave-length ($v \propto \sqrt{L}$). Therefore, the amount of retardation will give the depth of the ocean over which it passes. The mean depth of the ocean between Japan and San Francisco, as thus determined, is 12,000 feet; between Arica and Hawaii it is 18,000 feet.

Determination of the Epicentrum and Centrum.—By means of seismometers the direction of the earth's motion may be determined. If this be taken in many places, and the lines of direction be protracted, they will be found to meet at some point from which all seem to radiate. This is the center of the circular surface-waves or epicentrum. Or, by accurate clocks in many stations, the *time* of arrival of the shock may be recorded. If, now, we draw a line through all the places where the *time of arrival was the same,* we shall have a curve which represents the form of the wave and the center of which, *a,* is the epicentrum. Such lines of simultaneous arrival of shock are called coseismal lines (*c s,* Fig. 85).

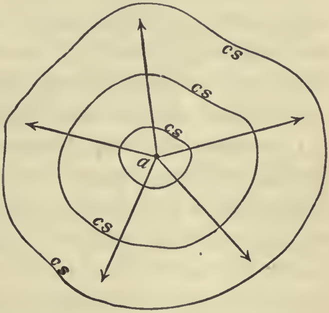

FIG. 85.

The position of the centrum or origin is much more difficult to find, but has been approximately found for several earthquakes. The general conclusion thus arrived at is that an earthquake focus (centrum) is usually only six to ten miles in depth, and that the shock is a jar produced by the formation of a great fissure.

Connection of Earthquakes with Phases of the Moon.—By careful comparison of the times of occurrence of thousands of earthquakes, it has been shown—1. That they are a little more frequent when the moon is on the meridian than when on the horizon. 2. Also at new and full moon than at half moons. 3. Also when the moon is nearest the earth than when she is farthest away. Now, these are the times of flood-tide, and of high flood-tides, and of highest flood-tides. Some have imagined that these facts prove the existence in the interior of the earth of a general liquid subject to tides. But the argument is evidently valueless, for any force tending to lift and break up the crust of the earth would be assisted by the gravitation or lifting power of the moon in passing the meridian, and this lifting power would be greatest at the times indicated above. Suppose, then, an interior force, tending to elevate and break the crust, constantly increasing but resisted by the rigidity of the crust: it is evident that, when the two forces are nearly balanced, the lifting force of the passing moon might well determine the moment of fracture. The moon does not produce the earthquake, but only determines the moment of its occurrence—only adds the last feather that breaks the camel's back.

Connection with Season and Weather.—By the discussion of the times of occurrence of a large number of earthquakes it is found that they are a little more frequent in winter than in summer. No cause for this is known.

Again: It is a popular belief that the occurrence is usually associated with an oppressive feeling of the atmosphere, or with storms. These meteorological phenomena are usually attended with a low condition of the barometer. Now, a low barometer means *diminished pressure of the atmosphere,* and this, again, might determine the moment of fracture of the crust. But this, like the attraction of the moon, must be regarded, not as the *cause* of the earthquake (which undoubtedly lies wholly within the earth itself), but only as sometimes determining the moment of its occurrence.

SECTION III.—GRADUAL OSCILLATIONS OF THE EARTH-CRUST.

The movements included under this head are on a grand scale, perhaps affecting whole continents, but usually so slow as to escape popular observation. But, though so inconspicuous, they are the most important of all forms of igneous agency, since it is by movements such as these that continents and sea-bottoms, mountains and great valleys, have been formed. Volcanoes and earthquakes occur suddenly, fill the mind with terror, and pass away, leaving behind little effect on the configuration of the earth ; but gradual movements of the crust, acting over large areas, and without ceasing, through inconceivable ages, have produced all the great inequalities of the earth's surface. Thus is it always—the causes producing the most far-reaching effects are ever those which, acting slowly, but everywhere and at all times, are scarcely recognized except by the thoughtful mind.

But although the effects of this form of igneous agency are so important, yet they are so obscure, and so little has been accomplished by them in the present geological epoch, that little is known of them, and our account must therefore be brief. It is their accumulated effects through all geological times, as shown in the structure and configuration of the earth, that alone are conspicuous. These we shall treat of in Part II. In the meantime, however, a few examples of their action *now* will prepare us for the discussion of these effects.

Elevation. — 1. *South America.*—We have already mentioned (page 157) that in 1822 and again in 1835, after severe earthquakes, the southwest coast of South America was elevated several feet along a line of many hundreds of miles. It is not probable that very much is accomplished in this paroxysmal way, but the fact is important as showing the connection of earthquakes with bodily elevation of large tracts. Suppose, then, any force beneath tending to elevate the southern end of the South American Continent, but resisted by the stiffness of the crust : if the crust yielded gradually as the force accumulated, only gradual elevation would take place; but if the stiffness was very great, the yielding might take place paroxysmally, by fracture, earthquake, and *sudden* elevation. The normal process is, gradual elevation by gradual yielding. Earthquakes are but occasional accidents in the slow march of these grand effects.

But, besides these *sudden* elevations, there has been during an immense time a *gradual* elevation of the whole southern part of the South American Continent out of the sea. The evidence of this is seen in the old beach-marks one above another to the height of 1,300 feet above the sea and extending along shore 2,000 miles on the western and 1,100 miles along the eastern coast. More recently, A. Agassiz has found on the same coast dead corals of recent species sticking to the rocks 3,000 feet above sea. Here, then, we have continent-making forces at work on a grand scale. It is not probable that the whole of these effects was accomplished during the present geological epoch, but they are the more interesting on that very account, since we here trace geological causes directly into causes now in operation.

2. *Italy.*—The most carefully observed example of gradual elevation is that at the Bay of Baiæ near Naples. Fig. 86 is a map of the Bay of Baiæ. From the present shore-line there runs back a flat plain of stratified volcanic matter sloping gently to the sea, called the *Starza;* this is terminated by a perpendicular cliff. In the vicinity are evidences of volcanic action in the form of volcanic cones and solfataras of very recent origin. Fig. 87 is a section of the same.

Now, there is abundant proof that this coast has slowly sunk and risen again at least twenty feet, and that this has all taken place certainly since Roman times, and probably since 1200 A. D. The evidence is briefly as follows: 1. The Starza consists of stratified material containing recent Mediterranean shells. 2. The cliff which terminates the Starza is obviously an old shore-cliff. 3. The face of this cliff up to a line twenty feet above sea-level is riddled with holes bored by ***lithodomi,*** a species of marine-boring shell. 4. On the Starza have been found the remains of an ancient Roman temple. When found, only the upper parts of three fine columns were visible, but, by removal of the soil twelve feet deep, a beautiful tessellated pavement and many broken columns were exposed. The pavement and buried portions of the columns were smooth and well preserved; then followed nine feet riddled with lithodomi, above which it was again smooth. The uppermost borings were on the same level as those on the cliff, and therefore mark the former level of the sea. Inscriptions on the pavement show that the temple was repaired in the third century, and it was *then,* therefore, *above sea-level.* The limit of the borings shows that it subsequently sank twenty-one feet, and again rose slowly to the original level, for the floor is now above sea-

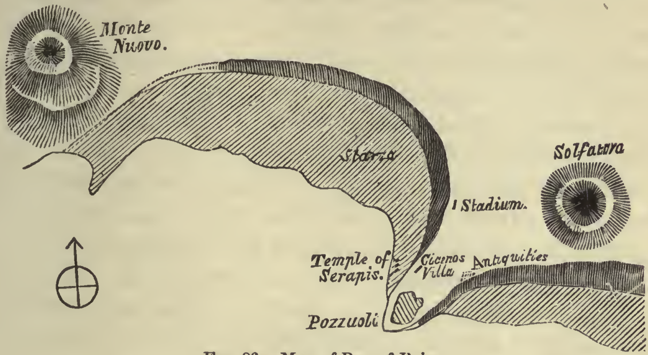

FIG. 86.—Map of Bay of Baiæ.

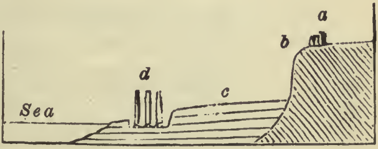

FIG. 87.—Section of map of Bay of Baiæ.

level. All this was done so quietly that it was unremarked by contemporaneous writers.

There is good reason to think that the whole took place between A. D. 1200 and 1600. Writers of the sixteenth century say that in 1530 one might stand on the cliff, *b*, and fish in the sea; this, therefore, was during the period of subsidence. Now, in 1198 a great earthquake destroyed Pozzuoli, and in 1535 Monte Nuovo was formed by eruption. It is probable, therefore, that the history of events was briefly this: After the earthquake of 1198, the sinking commenced, and continued until it reached twenty-one feet; it remained in this condition until the eruption of 1535, when it began to rise again. During the interval of subsidence, sediments, volcanic ashes, etc., filled up the bottom twelve feet deep, and protected the lower part of the columns, and only the part representing clear water was bored.

Other evidences of movements up or down are found all along the coasts of the Mediterranean. The ruins of the Temple of the Nymphs are now in water. The bridge of Caligula is bored several feet above the sea-level, etc.

3. *Sweden and Norway.*—The examples thus far given are in volcanic countries, and possibly caused by volcanic forces; but such movements are by no means always associated with volcanism; for example, Scandinavia is remarkably free from volcanism, and yet the whole coast, both on the Atlantic and the Baltic side, has been for a long time, and is still, rising out of the sea. The rate is less in the southern part and increases northward, the average being about two to three feet per century. That this has been going on for a long time is shown by old beach-marks at various levels up to six hundred feet above sea-level, showing an elevation to that extent, and that *during the present geological epoch.* At the rate of two and a half feet per century, this would require two hundred and forty centuries, or twenty-four thousand years.

This is of course only an approximate estimate, but we may say with confidence that for thousands of years the whole of Scandinavia, and perhaps much more, has been rising bodily out of the ocean.

Subsidence.—1. *Greenland.*—The coast of Greenland, for six hundred miles, is now subsiding, but at what rate is not known. The subsidence is proved by the fact that the houses built by the early Norwegian discoverers are now partially submerged. The fact is so well recognized by the Eskimos that they never build near the sea-level.

2. *River Deltas.*—In all great river deltas and perhaps we might say in all places where abundant sediments are accumulating, the earth-crust subsides as if weighted down with the ever-increasing load. In digging or boring into the delta of the Mississippi, the Ganges, or the Po, the deposit is found to consist of an alternation of river sediments with old forest-grounds, and sometimes peat several feet thick, and occasional layers of limestone. This is represented in Fig. 88, in which *s s* is the surface,

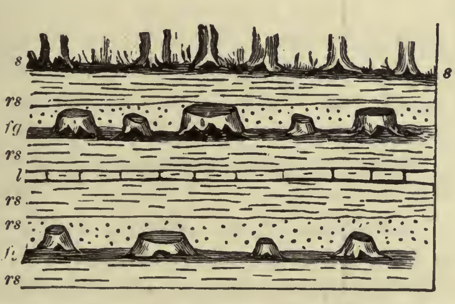

Fig. 88.—Section of river delta. *ss*, surface ; *rs*, river-silt ; *fg*, forest-ground ; *l*, limestone.

with growing vegetation and accumulated vegetable mold, and perhaps peat. As we go down we pass through river-silt, *r s*, then an old submerged forest-ground, *f g*, with black mold and stumps in place, as they grew, sometimes with a considerable layer of peat, then more river-silt, with an occasional layer of limestone, and so on, several times repeated. Such old forest-grounds have been found in the Mississippi delta fifty feet below sea-level, and in the Ganges layers of peat fifty feet below sea-level, and fresh-water shells and river-silt near four hundred feet. In the delta of the Po, peaty layers are found four hundred feet below sea-level (Lyell).

Now, the only way possible to explain these facts is to suppose a slow *subsidence* on the one hand and the upbuilding by sedimentation on the other, but not always absolutely at the same rate. When the upbuilding prevailed, the area was reclaimed and overgrown with forest. When the subsidence prevailed, the trees were submerged and destroyed, rotted to stumps and buried in sediments. Sometimes the subsidence was so rapid that salt-water conditions prevailed and limestones were formed. *Submerged forests* are found not only in deltas, but also on many coast-lines, and are among the surest signs of submergence.

3. *Mid-Pacific Bottom.*—But the grandest example of subsidence, still in progress, is undoubtedly that already discussed under coral reefs. As already shown, we have evidence that over an area of 10,000,000 square miles in mid-Pacific there has been, in comparatively recent geological times, a subsidence of 10,000 feet, and that the subsidence is still going on. Surely, in this case, we have changes now in progress which are of the nature of those by which continents and sea-bottoms were formed.

4. *River-beds.*—Our examples thus far are all from the coast region. The phenomena are plainest there, because we have the sea-level as a term of comparison. But in the interior of continents we have river beds as indicators of movement. We have seen (p. 28) that in a rising country rivers cut deeper, while in a sinking country they build up by deposit.

Cause of Crust Movements.

It is evident that the thing actually observed is only changes in the *relative level of sea and land.* In the interior of continents we have no means of determining such movements, except by river beds, as just explained. The cause of these slow changes is very obscure and can not be discussed here.* Suffice it to say that the great inequalities of the earth's crust, such as continents, ocean basins, and mountain chains, are probably due to the slow cooling, unequal shrinking, and consequent slight deformation of the whole earth, progressive through all geological time.

General Retrospect.

We have discussed briefly the agencies now in operation on the earth's surface, producing structure and form under our eyes. We believe that similar agencies have been at work through all time, and left their effects in the structure and surface forms which we actually find. We study the small and insignificant effects now produced in order that we may throw light on those greater effects which, accumulating through all geological times, are now embodied in the earth's structure. We are now in a position to examine the actual structure and forms of the earth, and to interpret them by the light of the previous discussions.

Again: Of the agencies which we have been discussing there are manifestly two groups. Atmospheric, aqueous, and organic agencies constitute the one, and igneous agencies the other. The one group tends to reduce the inequalities of the surface, and, acting alone, would eventually bring all to sea-level, and are therefore called *leveling* agencies. The other originally caused, and has ever tended to increase, the inequalities of the surface, and, acting alone, would ere this have made them of incredible dimensions, and are therefore called *elevating* agencies. The state of the contest between these two opposite forces at any time, determined the distribution of land and water, the height of continents and mountains, and depth of seas, at that time. The one group *roughhews,* the other *shapes,* the forms of the earth.

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* For fuller discussion, see the author's "Elements of Geology," p. 131.

PART II.

STRUCTURAL GEOLOGY.

CHAPTER I.

GENERAL FORM AND STRUCTURE OF THE EARTH.

General Form.

The general form of the earth is that of an oblate spheroid flattened a little at the poles. In other words, it is an ellipsoid of revolution about its minor axis. The equatorial diameter is about twenty-six miles greater than the polar diameter. This general form is taken at sea-level, the land-surfaces rising above and the sea-bottoms sinking below. This form is precisely that which a liquid globe would inevitably assume under the influence of rotation. It has, therefore, been somewhat hastily concluded that this general form is demonstrative evidence of the early incandescent liquid condition of the earth. It is certain, however, that the earth would have assumed this form by rotation, whether it were originally liquid or solid.* Therefore, while it is almost certain, from other considerations, that the earth was once liquid, and assumed its oblate spheroid form in that condition, yet this general form alone can not be regarded as proof of that condition.

General Structure.—We have already stated (page

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* This subject is more fully explained in the author's "Elements of Geology."

132) that the interior temperature of the earth increases 1° for every fifty-three feet in depth, and that at this rate the fusing temperature of rocks would be reached at about thirty miles; and, finally, that many have thence hastily concluded that the general structure of the earth is that of a globe of fused rock or lava, covered with a thin shell thirty miles thick. But we have also shown there the untenableness of this view. There are only two other views possible, and now held. Some hold that the earth is *truly solid* throughout, excepting reservoirs of liquid matter forming the foci of volcanoes. Others hold that the earth consists of—1. *A solid nucleus*, which forms its greatest part; 2. *A solid crust*, comparatively thin; and, 3. Separating these, *a sub-crust layer* of liquid or semi-liquid matter, if not universal, at least over large areas. There are many geological phenomena which seem to make this last view most probable.

Density of the Earth.—The mean density of the earth, taken as a whole, is 5.6. The density of the crust is about 2.5. Therefore the density of the central parts must be very much greater than 5.6. It is probably not less than 15 to 16. This greater interior density is due partly to a *difference of material* (the denser settling toward the center, while the earth was still in a fused condition), and partly to *condensation by pressure.*

Crust of the Earth.—The surface portion of the earth differs in many respects from the interior, and is, therefore, properly called a *crust:* 1. It is certainly a *lighter* portion covering a denser interior. 2. It is a cooler portion, covering an incandescent interior. 3. It is, as we shall see hereafter, a stratified portion covering an unstratified interior. 4. It is probably an oxidized portion covering an unoxidized or less oxidized interior (for oxidation comes by contact with air and water). 5. It is probably a solid shell covering a liquid or semi-liquid sub-crust layer. It is this idea of a solid shell covering a liquid which gave origin to the term *crust;* but the word is now used only to signify the superficial portions of the earth, subject to human observation, without any implication as to the interior condition.

Means of Geological Observation.—As thus defined, the crust is estimated at from ten to twenty miles in thickness. The manner in which we get a knowledge of the earth to that depth, or the means of geological observation, are—1. By *mines* and *artesian wells.* These penetrate 4,000 or 5,000 feet. 2. *Cañons* and *ravines.* These give sections of 6,000 or 7,000 feet. 3. *Volcanic ejections.*

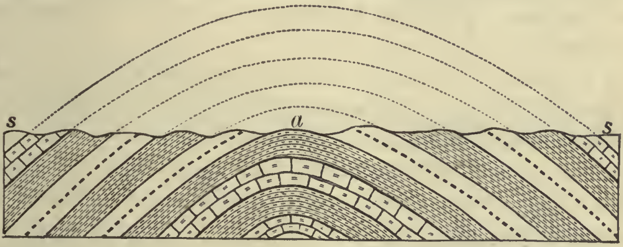


Fig. 89.

These bring up matter from unknown but certainly still greater depth. But the most common and effective means of observation is furnished by—4. *Foldings* of the crust, and subsequent *erosion.* In the section (Fig. 89) in which *s s* is the present surface, we represent one of the commonest of all geological phenomena. It is seen that from the point *a* the strata are repeated on the two sides. The dotted lines show how much has been cut away, and what depth of strata has been exposed to view. In this way, in very many places, the character of the rocks ten or more miles deep is revealed.

Our direct observation is absolutely confined to this superficial portion. We can only speculate about what is beneath. It would seem, at first sight, that this is an insignificant portion of the earth upon which to found a *science of the earth.* But it must be remembered that on this superficial portion has been enacted, and in its structure has been recorded, the *whole history* of the earth.

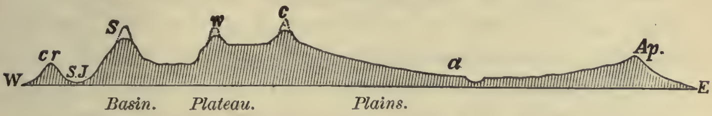
General Surface Configuration of the Crust.—The crust of the earth is diversified by greater and smaller features. The greater features are due to interior or *elevating,* the lesser to exterior or *leveling* agencies. Under the former head come those greatest features, constituting continental surfaces and oceanic bottoms, and those next greatest, viz., mountain-chains and great valleys. Under the latter come all those peaks and ridges, valleys and ravines, which have been produced by subsequent erosion.

The mean height above the sea-level of the continents is about 1,200 to 1,300 feet, or less than one fourth mile, and the mean depth of the ocean-bottoms below the same level is about 15,000 or 16,000 feet, or nearly three miles. The ocean-surface being nearly three times as great as the land-surface, it is evident that, if the inequalities of the crust-surface were removed, there is water enough to cover the whole earth more than two miles deep.

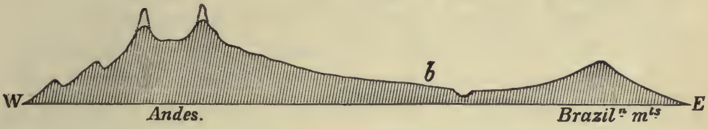
General Laws of Continental Form.—There are certain general laws of continental form which have a bearing on the question of the origin of continents, and which, therefore, must be briefly mentioned.

1. **Continents consist essentially of Interior Basins, with Coast-Chain Rims.**—The interior basins are drained by the great rivers of the world. This typical structure is well shown in America, North and South, in Australia, and in Africa. For example, in North America we have the great interior basin drained by the Mississippi River, bordered on the Atlantic side by the Appalachian, and on the Pacific side by the great Rocky Mountain system or American Cordilleras, consisting of many ranges, of which Colorado, Wahsatch, and the Sierra and Coast

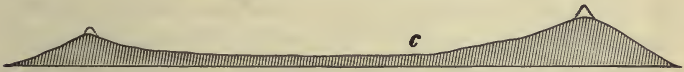
Range of California are the most notable (Fig. 90, *a*). South America has the Andes on one coast, the Brazilian mountains on the other, and the great interior basin drained by the Amazon, La Plata, and Orinoco Rivers (Fig. 90, *b*). Similarly, the great basin of Africa is drained by the Nile, Niger, Congo, and Zambesi Rivers.



East and west section of North American Continent: *cr*, coast range; *SJ*, San Joaquin plain; *S*, Sierra; *w*, Wahsatch; *c*, Colorado range; *Ap*, Appalachian.



East and west section across South America.



East and west section across Australia.

Fig. 90.—Sections across North and South America and Australia.

Australia is also a fine example, as shown in Fig. 90, *c*. Europe and Asia have similar structure, but less perfect. This continent is elongated east and west, and therefore the section must be north and south.

2. **The Greater Range faces the Greater Ocean.**—In America, the North American Cordilleras and the Andes face the Pacific, while the Appalachian and the Brazilian mountains face the Atlantic. In Africa and Australia, on the contrary, the east range faces the greater ocean, and is the greater.

3. The greater chains are usually the most complex and crumpled in structure, and give evidence of greatest volcanic activity in the present or in the past.

4. Continents and ocean-bottoms have not, as some imagine, frequently changed places. On the contrary, the places of continents have been indicated and their outlines sketched out from the beginning, and their forms have been gradually developed, though with many oscillations, throughout all geological times.

The origin of continents and ocean-bottoms is very obscure, but it is probably in some way connected with the *unequal contraction* and therefore *deformation* of the spheroidal form of the earth, by slow cooling from a former incandescent condition. In such an irregular or deformed spheroid, of course, the water would collect in the hollows, and the protuberances would become continents. The origin of mountains we discuss further on.

Rocks.

Definition of Rock.—The term *rock* is used in popular language to designate any substance of stony hardness. Not so in geology. Any substance constituting a portion of the earth's crust, whether it be hard or soft, is called a *rock*. No distinction based on hardness alone is of any value. The same sandy bed may be found in one place hard enough for building-stone, and in another soft enough to be spaded. The same clay stratum may sometimes be traced from a condition of slaty hardness in one place to good brick-earth in another ; the same bed of lime from marble into chalk, and the same volcanic eruption from stony lava into a bed of volcanic ashes.

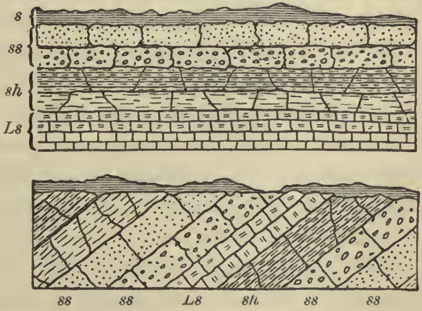
Classes of Rocks.—Rocks are divided, according to their structure and origin, into two principal kinds, viz., *stratified* and *unstratified*. *Stratified* rocks are more or less consolidated *sediments*, and are therefore *aqueous* in origin and earthy in structure. Unstratified rocks have been more or less *fused*, and therefore are *igneous* in origin and either crystalline or glassy in structure.

CHAPTER II.

STRATIFIED ROCKS.

SECTION I.—THEIR STRUCTURE AND POSITION.

LET any one examine the rocks of a quarry of limestone or sandstone, and he will find that the stone lies in regular beds. In some places these beds will lie level (Fig. 91), in other places they may be inclined (Fig. 92). For example, throughout the valley of the Mississippi they are usually level, while in mountain-regions they are usually inclined. The next most conspicuous structure will probably be the cross-divisions called *joints*, by which the beds are broken into separable blocks. These are found in all rocks, are not characteristic of stratified rocks, and therefore we say nothing more about them now. On examining a little more closely, the beds will be seen to be subdivided by faint lines similiar to those observed in a section of sediments, and known to be produced by the sorting power



FIGS. 91, 92.—Sections of horizontal and inclined strata: *s*, soil; *ss*, sandstone; *sh*, shale; *Ls*, limestone.

of water (page 27). In a word, the mass exposed on a cliff or in a quarry, or any large section of stratified rock, is seen to be divided by parallel planes into thick beds of different kinds of materials, as sandstone, limestone, etc., and each of these, probably, into thinner beds, differing perhaps in grain or color, and finally these again into thin sheets, produced by the sorting of material. Now, the larger beds are called *strata,* the subdivisions of different color or grain, *layers,* and the lines of sorted materials are *laminæ.* These terms are loosely used, but always in the order mentioned, and the word lamina is always used to signify the marks of water-sorting. Now, the structure we have described is called *stratification,* and such rocks *stratified rocks.*

Extent and Thickness.—Stratified rocks cover at least nine tenths of the land-surface, and even where they do not occur it is only because they have been removed by erosion or else covered by igneous rocks. Since, as we shall see presently, stratified rocks were formed at the bottom of the water, it is evident that there is no portion of the earth which has not been at some time covered by the sea. The extreme thickness of these rocks is probably ten to twenty miles; the average thickness is certainly several thousand feet.

Principal Kinds.—As defined above, stratified rocks fall naturally into three great groups: 1. *Arenaceous* or sand-rocks; 2. *Argillaceous* or clay-rocks; and, 3. *Calcareous* or lime-rocks. These may be either in a soft or in a stony condition.

The *sand-rocks,* in their soft or incoherent condition, are beds of sand, gravel, and pebbles or shingle. In their coherent or stony condition they are sandstones, grits, and conglomerates. Breccias differ from conglomerates only in having the fragments angular instead of rounded. They consist of rubble, instead of pebbles, cemented together.

The *clay-rocks,* in their incoherent condition, are beds of clay, brick-earth, mud, and ooze. In their coherent condition they are the same cemented into *shales,* or, still harder, into *slates.*

Lime-rocks, in an incoherent condition, are lime-muds, such as exist now in coral lagoons, or in the deep sea (globigerina ooze, page 117); in a slightly consolidated condition they are chalks, and in a stony condition they are limestones, marbles, and travertines.

These different kinds may each produce varieties of different color and grain. They also pass by mixture insensibly into each other, and thus form infinite varieties. Thus we may have an argillaceous or calcareous sandstone or calcareous shale, etc.

All that need further be said on the subject of the origin of stratified rocks is best thrown into a series of propositions, very simple and yet underlying all geological reasonings:

1. **Stratified Rocks are more or less Consolidated Sediments.**—This has been thus far assumed. We wish now to direct the pupil to the observation of the evidence: *a.* Every gradation may be traced between muds, clays, and sands, which we know were deposited in water; and shales and sandstones, which we find forming the strata of mountains. *b.* In many cases we may see the process of hardening going on under our eyes. For example, at the mouths of rivers carrying lime in solution, like the Rhine, the river-silts are consolidated into *calcareous shales.* On the shores of coral reefs we find coral mud, coral sand, and coral breccia consolidated into peculiar limestones (page 108). *c.* Close examination of many rocks, especially sandstones and shales, clearly shows the sorting of material (water-sorting) along the lines of lamination. *d.* As shells and skeletons of animals are now imbedded in muds of rivers, lakes, and seas, so fossils are found in stratified rocks. *e.* Other marks, which occur

in recent sediments, such as ripple-marks, rain-prints, sun-cracks, foot-prints of animals, etc., are also found in the hardest stratified rocks. In a word, it may be said that *every mark or peculiarity which has been observed in recent sediments has been found also in stratified rocks.*

We may assume, then, as certain that stratified rocks are sediments formed originally at the bottom of seas, lakes, rivers, etc., and that when we find them far in the interior of continents and high up the slopes of mountains we have indubitable evidence of great changes of level.

Stratified rocks are all deposits in water. Sandstones and shales are the *débris* of erosion, and are therefore *mechanical deposits;* and these rocks are often called *fragmental* rocks, because they are made up of the fragments of previous rocks. Limestones, on the other hand, are either organic or chemical deposits. Again, sandstones, grits, and conglomerates are formed by violent action, and they indicate either rapid currents or exposed shores ; shales indicate quiet seas or bays ; limestones, open seas.

We have already seen (page 27 *et seq.*) that sediments are transported soils, and (page 10) that soils are disintegrated rocks. Now, we see that stratified rocks are consolidated sediments. We have here an example of a perpetually recurring cycle of changes : rocks are decomposed into soils, soils are carried and deposited as sediments, sediments are again consolidated into rocks, to be raised into land-surfaces, and again disintegrated into soils—and so the cycle goes round.

The cause of consolidation is sometimes only the *pressure* of great thickness of sediment ; sometimes the same, aided by gentle heat ; sometimes there is a distinct cementing substance, the most common being lime carbonate and silica. When there is a cementing substance, the process is often rapid, and may be observed ; as, for example, in the formation of coral rock. But in other cases the process is very slow, and therefore the newer rocks are often, though not always, imperfectly consolidated.

2. **Stratified Rocks have been gradually deposited.**—By this we mean that they have not been formed at once, as some of the older geologists imagined, but by the *regular operation* of causes similar to those now accumulating sediments. The slowness was sometimes extreme. For example : *a.* We have strata in which the laminæ are as thin as paper, and yet each one represents recurring conditions, as ebb and flow of tide, or flood and low water of rivers. *b.* In some cases we have a shell attached to the inside of another shell (Fig. 93), in such wise that the latter shell must have been dead before the former attached itself. In such cases a half or quarter inch thickness of rock represents the whole life of the second shell. *c.* We have seen that some limestones are made up of the accumulated remains of successive generations of microscopic shells (page 115). Every inch thickness of such deposit must represent a long period of time. And yet such deposits are often hundreds or even thousands of feet in thickness. These are, however, extreme cases of slowness. As a general rule, coarser materials are deposited more rapidly than finer—e. g., sands than clays and limestone, but all by regular operation of causes; and therefore, making due allowance for the nature of the materials, *thickness* is a *rough measure of time.*

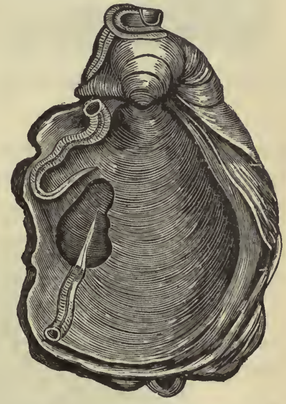


FIG. 93.—Serpulæ on interior of a shell.

3. **Stratified Rocks were originally horizontal at the Bottom of the Water.**—This is a necessary conse-

quence of the manner in which they were formed. Therefore, when we find them in *other positions* and at *other levels,* we conclude that they have come so by *subsequent change.*

We must not imagine, however, that the planes between the strata were ever absolutely horizontal. Strata must not be likened to continuous, even sheets, but rather to extensive cakes, thickest in the middle and thinning on the margins and there interlapping with other strata or cakes (Fig 94). Coarse materials, like sandstones and grits, are more local, and thin out more rapidly, while fine materials, like clays, are often very widely continuous. This thinning out of strata, however, does not interfere seriously with their appearance of evenness at any point of observation.

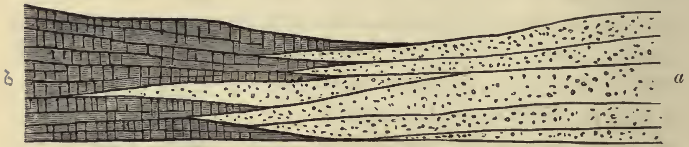


FIG. 94.—Diagram showing thinning out of beds: *a*, sandstones and conglomerates; *b*, limestones.

Another more important apparent exception to original horizontality is what is called *cross-lamination* or *false-bedding* (Fig. 95). These are liable to be mistaken for

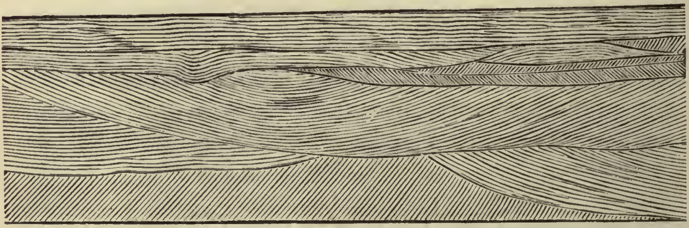


FIG. 95.—Section on Mississippi Central Railroad at Oxford (after Hilgard): oblique lamination.

tilted strata. But it will be observed that it is the laminæ, and not the strata, which are inclined. And, moreover, their extreme irregularity is sufficient to distinguish them from true inclined strata. They seem always to be produced by deposit from rapid, shifting, overloaded currents, and are, therefore, common in *river-deposits.*

After explaining these apparent exceptions, we come back with still more confidence to the proposition that stratified rocks were originally *soft sediments* in a *horizontal position* at the *bottom of seas, lakes,* etc. But we usually find them *now* in an entirely different condition and position. We indeed find them sometimes soft, but more commonly *stony;* sometimes, indeed, still horizontal, though raised above the sea and in the interior of continents, but more commonly more or less tilted; sometimes, especially in mountain-regions, not only tilted, but folded, crushed, contorted, broken, and dislocated in the most complex manner, so that it is difficult to make out their natural order. Sometimes the contortion is in the *laminæ,* so that it can be seen in a hand-specimen (Fig. 96). Sometimes a *series of strata* are folded together, such as may be seen at one view on an exposed cliff (Fig. 97). Sometimes the strata composing the *crust of the*

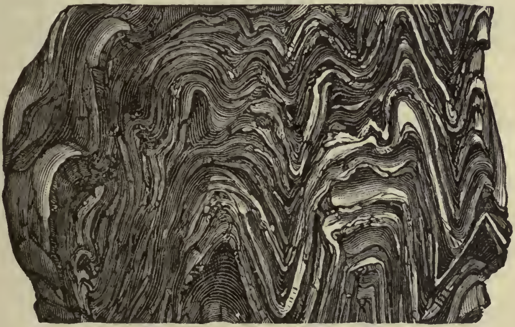


Fig. 96.—Crumpled laminæ. (After Geikie.)

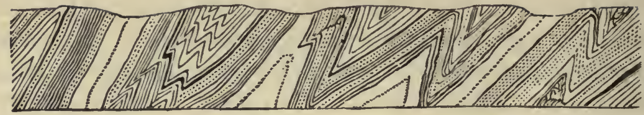


FIG. 97.—Contorted strata. (From Logan.)

earth, several thousand feet thick, are folded all together so that their foldings form great mountain-ridges, and can only be made out by extensive surveys (Fig 98). As might be expected, the strata by such violent movements are usually broken and dislocated, and always, as seen in Figs. 97 and 99, large portions of their upper parts have been carried away by erosion, leaving their edges exposed on the surface. Such exposure of strata on the surface is called *outcrop.*

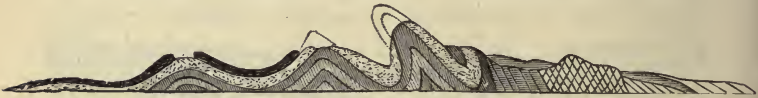


FIG. 98.—Section of Appalachian chain.

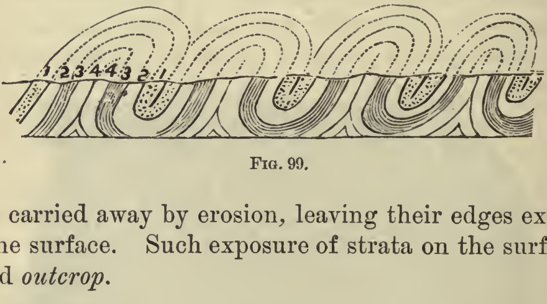


FIG. 99.

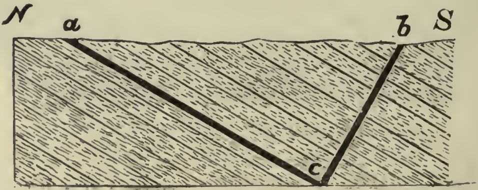


FIG. 100.

This important subject must be taken up with some detail, and for this purpose it becomes necessary to define some common geological terms.

Dip and Strike.—The angle of inclination of strata with the horizon is called the *dip*. There are always two elements to be considered; viz., *direction* and *amount.* Thus a stratum may dip northward 30°. The angle of dip varies from 0 to 90°—i. e., from horizontality to verticality. Sometimes strata are even pushed over beyond the vertical—such are called overturn-dips (Fig. 99). Examples are found in all great mountain-chains, especially in the Alps. When strata dip regularly, their thickness may be easily estimated. For example, in walking from a to b (Fig. 100), we pass over strata whose thickness is $b\ c$ ($= a\ b\ .\ \sin b\ a\ c$). The dip may be accurately determined by means of a clinometer (Fig. 101).

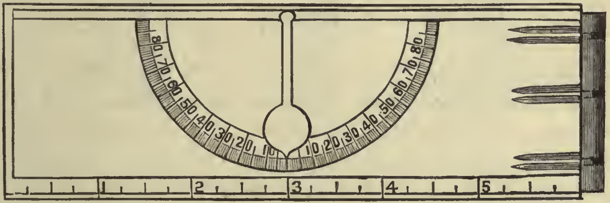


Fig. 101.—Clinometer.

The direction of strata, or their line of intersection with a horizontal plane, is called the *strike*. It is always at right angles to the dip. If the dip is so many degrees north or south, the strike will be east and west. If the surface of the ground is level, the strike will be the same as the outcrop, or appearance on the surface, of the strata; but this is seldom the case. If the strata are plane, the strike will be a straight line. If the strata are folded, the strike may be very sinuous (Fig. 107). In a map view of strata, the dip and strike are represented by the sign ↥, in which the heavy line represents the strike, and the perpendicular the dip (Fig. 105). The perpendicular is made shorter, as the dip is at a higher angle.

Anticline and Syncline.—When a series of strata dip in one direction in one place, the same series will usually be found to dip in a contrary direction in another place. In other words, strata are usually disturbed by *lateral pressure,* which throws them into *folds,* sometimes wide and gentle, like undulations, sometimes closely appressed. Thus strata usually occur in alternate saddles and troughs (Figs. 102, 103). The saddles are called *anticlines,* the troughs *synclines.* An anticlinal axis, then, may be defined as a line on either side of which the strata repeat one another, dipping in opposite directions, *away from* the axis. A synclinal axis is a line on either side of which the strata repeat each other, dipping in opposite directions, but *toward* the axis. In Figs. 102 and 104, *a* is an anticline, and *s* a syncline.

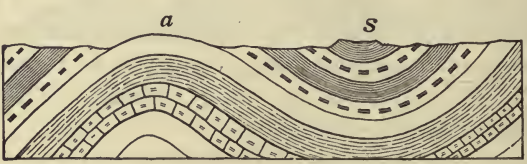


FIG. 102.

In anticlines the *strata* lie in saddles and in synclines in troughs, but the surface configuration of the ground may or may not correspond. Sometimes the ground is comparatively level, though the foldings are strongly marked (Fig. 102). Sometimes the anticlines are ridges, and the synclines valleys (Fig. 103), and sometimes the

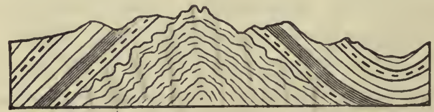


FIG. 103.

reverse (Fig. 104). In gently folded strata it is very common to find the configuration reversed on the surface,

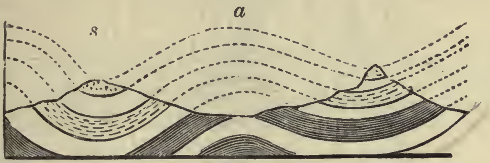


FIG. 104.

i. e., synclinal ridges and anticlinal valleys. Examples of these are given on page 248.

Folded strata, which are tilted *only by folding,* will outcrop on level ground in parallel bands, as in Fig. 105,

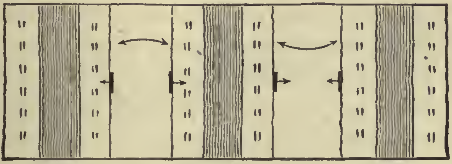


FIG. 105.

which is a map view of Fig. 102. But if the whole be again tilted in a direction at right angles to the folds,

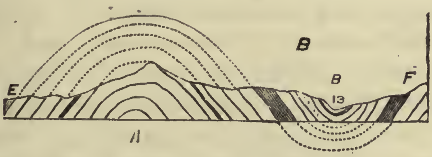


FIG. 106.—Section of undulating strata.

then the map of outcrop will be sinuous. Fig. 106 is a section of folded strata thus tilted, and Fig. 107 is a map of the same. The section is along the line *C D*. Examination of the signs of dip will explain the map.

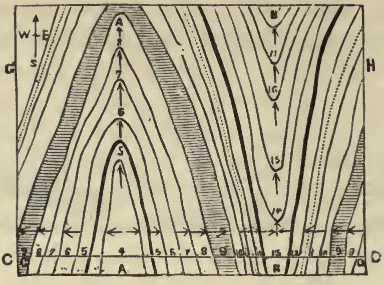


FIG 107.—Plan of undulating strata.

We have spoken of folded strata and the way in which they outcrop; but in a survey the process is reversed, i. e., it is the outcrop which is observed, and from this we construct the section. Now, when we remember the complex folding, then the tilting after folding, then the displacement by fractures, and then, worst of all, the covering of the whole deeply with soil, leaving exposed only patches here and there, we can easily see how difficult a problem it often is to construct a section of the stratified rocks of a country. If the strata be exposed on a cliff or a cañon-side, there is little difficulty, but, in the absence of such, the geologist takes advantage of every exposed patch, examines every gulch or stream-bed, every quarry or railroad-cutting, and thus constructs an *ideal section*.

Conformity and Unconformity.—We have just seen that the strata composing the country rock of a land-surface are usually tilted and crumpled and always eroded, so that their edges are exposed (see Figs. 106, 107). But we have also seen (pages 164–170) that in some places land-surfaces are now sinking beneath the sea, and in others sea-bottoms are rising to become land-surfaces. The same is true for all geological epochs. Now, suppose at any time an eroded land-surface sank below sea-level so that sediments were deposited on the eroded edges and filling the erosion-hollows of the strata, and finally the whole was again raised above sea and exposed to the inspection of the geologist; the phenomena which would

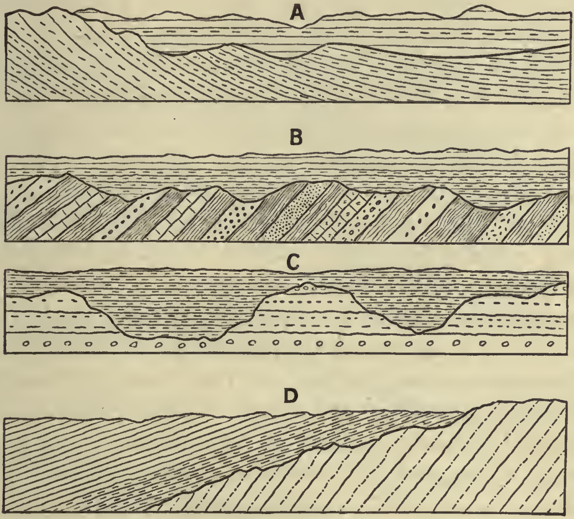


Fig. 108.—Some cases of unconformity.

be observed are represented by Fig. 108, *A, B, C.* This is what is called *unconformity.* More commonly in such cases there is a want of parallelism between the two series of strata, as in Fig. 108, *A, B.* But this is not necessary. Fig. 108, *C,* represents unconformity no less than *A* and *B.* In the one case the strata were raised into land-surface and at the same time folded and tilted, and then eroded; in the other case, they were raised and eroded without folding or tilting. Sometimes the *second raising* is also attended with tilting, in which case both series are tilted, but in different degrees, as in *D.*

Definition.—After this explanation, we are prepared to define. When a series of strata are parallel, as if formed continuously under similar conditions, they are said to be *conformable*. But if two series are discontinuous—i. e., separated by an erosion-surface or old land-surface, and therefore formed at different times and under different conditions—they are said to be *unconformable*. In all the figures the strata of the lower series are conformable throughout, and so are also those of the upper, but the two series are unconformable with each other, the line of unconformity being an old eroded land-surface.

Even so simple sections as Fig. 108, one of the commonest observed, record many interesting events in the history of the earth, viz.: 1. A long period of quiet, during which the first series of strata was deposited. 2. A period of commotion, during which the sea-bottom here was elevated into land, and perhaps the strata crumpled. 3. A long period during which it remained land-surface and was deeply eroded and the strata-edges exposed. 4. Another period of commotion, during which it sank again and became sea-bottom. 5. Another long period of quiet, during which the second series of strata was deposited; and, 6. Still another period of movement, by which the whole was finally raised and became thus subject to the inspection of the geologist.

The following diagrams (Fig. 109) represent the manner in which the phenomena may be supposed to have occurred. In *A*, we have thick sediments, *Sd*, accumulated on an off-shore sea-bottom. In *B*, the same have been elevated into land, and crumpled. In *C*, they have been eroded and their edges exposed. In *D*, they have again subsided beneath the sea, and received sediments, *Sd*, on their eroded edges.

Since geological history is mainly recorded in stratified rocks, and since, while a place is land-surface and being eroded, there can be no strata formed *there*, it is evident that a line of unconformity always indicates a period of which there is no record *at that place*, although the record may be found elsewhere. Unconformity, therefore, always represents *a gap* in the record—a lost interval of time—which may be very long, viz., the whole time during which the erosion was going on.

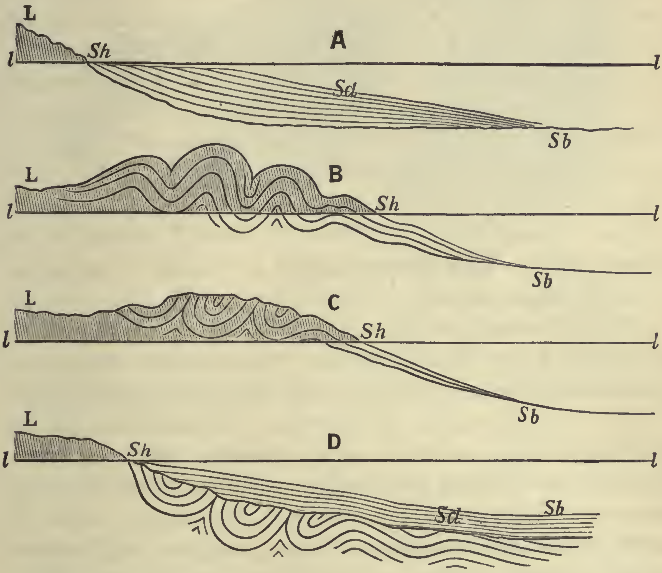


FIG. 109.—In all : *L*, land ; *ll*, sea-level ; *Sh*, shore-line ; *Sb*, sea-bottom ; *Sd*, sediments.

A group of conformable strata usually form a *geological formation,* and a line of unconformity usually separates two different geological formations. The division of the strata into formations, however, is based also on other characters, viz., the contained fossils. The subject will be taken up again under that head.

Cleavage Structure.

Stratification is an *original* structure, i. e., impressed at the time of deposit of sediments. Cleavage is a superinduced or *subsequent* structure, but it so simulates stratification that it seems best to take it up here. It is found in many kinds of rocks, but most perfectly in slates, and is therefore often called *slaty* cleavage.

Definition.—Cleavage is easy splitting in certain directions. There are many kinds of cleavage due to different causes. For example, many crystals split perfectly in certain directions. This is called *crystalline* cleavage, and is due to *molecular arrangement.* Certain stratified sands split easily into broad flag-stones in the direction of the laminæ. This is *lamination cleavage,* and is due to the arrangement of the grains by the *sorting power* of water. Again, wood splits easily in the direction of the silver grain. This *wood-cleavage* is due to the arrangement of the *wood-cells.*

Slaty Cleavage.—Now, there is also an easy splitting of rocks in definite directions, which occurs on an immense scale, and in certain slates is a very marked structure. The direction of cleavage is usually vertical or highly inclined. Whole mountains are thus cleavable from top to bottom, and rocks over thousands of square miles are often made up of such thin sheets. It is by splitting along these lines of easy fracture that roofing-slates, ciphering-slates, and blackboard-slates are made.

On casual examination of strata the cleavage-planes are liable to be mistaken for fine *laminæ,* and we are apt to think that we are examining a beautiful example of *highly inclined strata.* But a closer examination will usually show the lines of stratification running in an entirely different direction. In Fig. 110, the strong lines

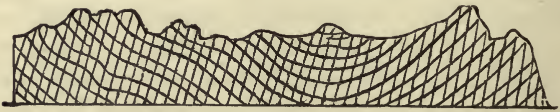


FIG. 110.—Cleavage-planes cutting through strata.

show the strata strongly folded, while the light lines show the cleavage nearly vertical, cutting through these

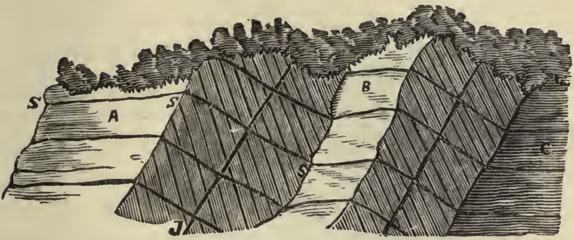


Fig. 111.—Strata, cleavage-planes, and joints.

in parallel planes. In Fig. 111, three kinds of structure, which should be kept distinct in the mind, are shown. The rectangular block-faces are joints; the strong lines, *s s*, slightly inclined to the right, are strata; while the highly inclined lighter lines are cleavage-planes cutting through both.

Cause of Slaty Cleavage.—Slaty cleavage is undoubtedly caused by a mashing together of the whole rock-mass in a direction at right angles to the cleavage-planes, and an extension in the direction of these planes; and, since cleavage-planes are usually nearly vertical, it is the result of a mashing together *horizontally*, and an *up-swelling* or extension *vertically* of the whole cleaved mass.

Proof.—This is proved (*a*) in field-observation by the folding of the strata (Fig. 110), and (*b*) in hand-specimens by the crumpling of the finest laminæ in the direction indicated above. Fig. 112 represents a block of slate eighteen inches long, in which the lamination-lines are shown crumpled by the pressure. In the position of the block it is evident that the crushing was horizontal. The cleavage-planes, represented by the light lines, are vertical. One cleavage-face, *c p*, is shown. The same is proved, also (*c*), by distorted fossils often found in cleaved slates (Fig. 113). By comparing the natural with the distorted form the direction of pressure is found to be always at right angles to the cleavage-planes, i. e., the fossils are shortened in that direction and elongated in the direction of the planes (*d*). In many slates, especially the purple Cumberland slates, much used in roofing, oblong greenish spots are common. If they be closely examined, they will be found to be *very thin* in the direc-

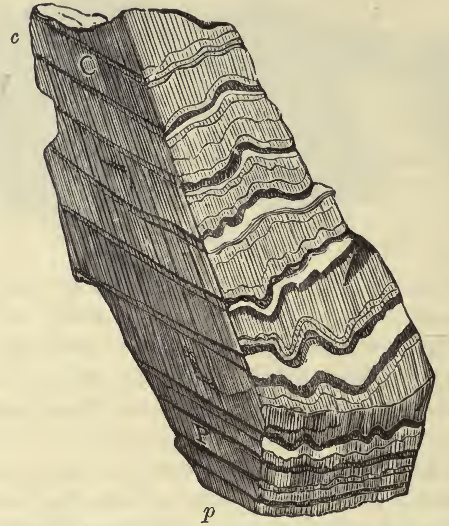


Fig. 112.—A block of cleaved slate. (After Jukes.)

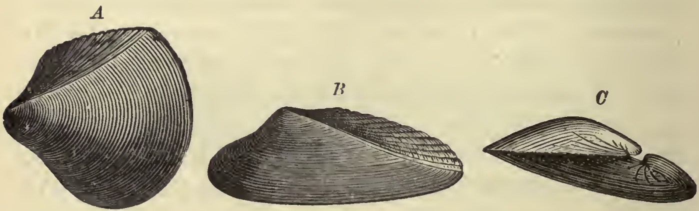


Fig. 113.—Cardium hillanum : *A*, natural form ; *B* and *C*, deformed by pressure.

tion of the thickness of the slate or at right angles to cleavage. On the cleavage surface the shape is broad, elliptical (Fig. 114, *A*), while on section the shape is very flat, *B*. These spots before mashing were *round pellets* of clay. They have been mashed into an ellipsoid of three unequal diameters, the longest, *a b*, in the dip of the cleavage, and therefore nearly vertical; the next, *c d*, in the strike of the cleavage, and therefore horizontal; and the smallest, *e f*, at right angles to cleavage. This proves that the whole mass has been mashed at right angles to cleavage, and extended in the direction of the dip of cleavage. Microscopic examination shows that every constituent granule of the original clay is in the slate mashed into a thin scale, so that the original granular structure is changed into a *scaly structure*, and it is this which determines the easy splitting.

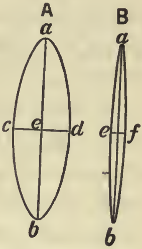


Fig. 114.—Flattened nodules: *A*, face-view; *B*, side-view.

Geological Application.—The amount of mashing together horizontally and extension vertically shown in these different ways is so great that an original cube or sphere in the unsqueezed mass is changed into an oblong, of which the shortest diameter is to the longest as one to three or four, one to five or six, one to nine or ten, and even sometimes as one to fifteen. The average in well-cleaved slates is one to six. Now, when we remember that thousands of square miles and thousands of feet thickness of rocks are thus affected, it is evident that this slow mashing together horizontally of whole mountain-regions must be an important agent in the elevation of land, and especially in the formation of mountains. We shall speak of this again under the head of mountains.

Concretionary or Nodular Structure.

This, also, is a superinduced structure simulating an original structure. As slaty cleavage simulates stratification, so concretions or nodules simulate and are apt to be mistaken for fossils.

In many strata, especially calcareous sandstones and shales, we find rounded masses often of curious shapes, separable from the general mass of the strata, and differing a little from it in hardness and composition. These are called concretions, nodules, septaria, etc. They have evidently been separated out of the general mass after the latter was deposited. This is shown by the fact that the planes of stratification often run right through them (Fig. 115).

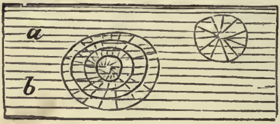


FIG. 115.

Forms and Structure.—In *form* they are sometimes perfectly spherical, like cannon-balls, and vary in size from that of a marble to many feet or even yards in diameter; sometimes flattened ellipsoidal, and these, when

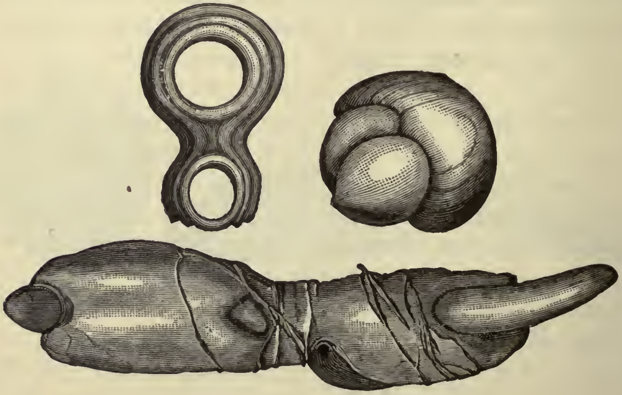


FIG. 116.—Nodules, from strata.

marked with polygonal cracks, simulate very much a turtle-shell, and are called turtle-stones ; sometimes dumb-bell-shaped, sometimes rings, sometimes all sorts of strange and fantastic shapes (Fig. 116). In *structure* they are sometimes *solid,* sometimes *hollow,* sometimes affected with interior cracks, sometimes have a concentric shell-structure, and sometimes a radiated structure.

These curious shapes so simulate fossils that even experienced geologists may sometimes be in doubt. By common observers they are very often mistaken for fossil nuts, fossil turtles, etc. They are, however, very interesting to the geologist, because they often contain a fossil beautifully preserved in the center.

How Formed.—They seem to be formed by the slow aggregation of more soluble or more suspensible matter from a general mass of insoluble matter, an organism often forming the nucleus of aggregation. Thus, if the mass be a calcareous sandstone, the lime will gather in places, forming sandstones containing more lime than the general mass. So calcareous clays form nodules of lime mixed with clay. These are the hydraulic-cement nodules. In chalk the disseminated silica seems to gather

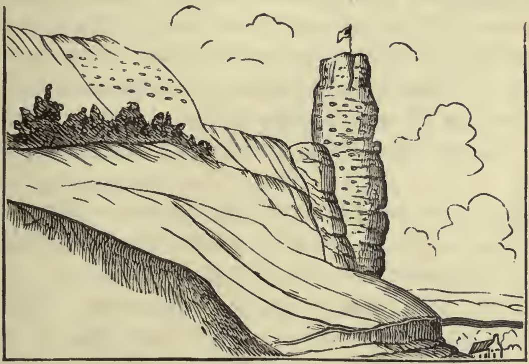


FIG. 117.—Chalk-cliffs with flint nodules.

into nodules of pure flint, and leave the chalk a pure carbonate of lime deprived of its silica. Hence, chalk usually contains flint nodules, scattered or in layers (Fig. 117).

We speak of this nodular structure not on account of its great importance, but because it is apt to strike the observing eye, and very apt, too, to be mistaken for fossils.

Fossils: their Origin and Distribution.

Every one must have observed that in many places the stratified rocks contain the exact *forms* of organisms, especially shells, though these seem to have *turned to stone.* These are called **fossils.** They are of extreme interest to geologists, because they reveal the nature of the former inhabitants of the earth. Stratified rocks are the consolidated sediments of former seas, bays, lakes, and rivers. Then, as now, shells lived in the ooze of sea-bottoms, or were cast up on beaches; the leaves and branches of trees and carcasses of land-animals were carried down by rivers to lakes and estuaries and buried in mud. These have been preserved, with more or less change, to the present day. A fossil, then, may be defined as any evidence of the former existence of a living thing. Next to lamination, they are the most constant characteristic of sedimentary rocks.

Degrees and Kinds of Preservation.—There are various degrees and kinds of preservation of organic forms. In some cases not only form and structure, but even the organic *matter* of soft parts, is preserved. More commonly, however, only the *shells* and *skeletons* of animals are preserved, and of these sometimes both the *form* and *structure,* and sometimes only the *form.* We shall speak of these under three heads:

1. **Organic Matter preserved.**—This, of course, is rare. The only perfect examples are those of carcasses

preserved in ice. In the frozen cliffs and soils of Siberia, the carcasses of extinct elephants and rhinoceroses have been exhumed by the rivers, in a condition so perfect that dogs and wolves fed on the flesh. In peat-bogs are found the perfect skeletons (still retaining the organic matter of the bones) of extinct animals; and in some cases even the flesh is preserved, but changed into a fatty substance (adipocere). These are all in comparatively recent strata. But, even in the oldest strata, organic matters of once living beings are preserved, though changed into coal, lignite, petroleum, bitumen, etc.

2. **Organic Structure preserved.**—This is the type of what is called petrifaction; it is best illustrated by petrified wood. In many strata, but especially in the sub-lava gravels of California (page 395) and the tufa beds of California and the Basin region, drift-wood is found completely changed into stone. In these we have not only the form, not only the general structure—i. e., bark, wood, and pith, concentric rings, medullary rays, and woody wedges—but even the minutest microscopic structure of tissue and markings on the walls of cells, perfectly preserved in the stony matter (usually silica) replacing the wood.

Mode of Petrifaction.—It must not be imagined that the wood is *turned* to stone, but is only *replaced* by stony matter. As each particle of woody matter passes away by decay, a particle of mineral matter is deposited in its place from solution, thus reproducing its structure perfectly. Wood best illustrates the process, but in a similar manner the minute structure of bones, teeth, corals, shells, etc., are preserved, even though the original matter is all gone. The most common petrifiers are silica and carbonate of lime.

3. **Organic Form only preserved.**—In many cases the structure is not preserved, but we find only a *mold* of the external form, or a *cast* of the same *in stone*. This is

best illustrated by the case of shells. The following figure is a diagram showing four different cases, all of which are very common. In the figure the horizontal lines represent the stony matrix in which the shell is formed, or *mud* in which the shell was originally buried, and the vertical lines represent the *subsequent filling* with finer material.

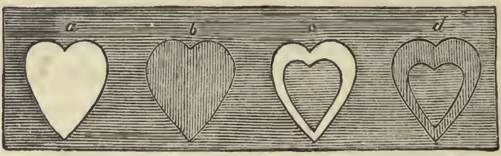


FIG. 118.—Section of strata containing fossils.

Explanation.—In case *a*, the *living* or *recently dead* shell was buried in mud, and afterward the whole organism was dissolved and removed, leaving only the hollow mold where it lay. In case *b*, we have the same, only the mold has been subsequently filled and a cast made by the deposit of silica or carbonate of lime from solution. If the rock be broken, the cast will often drop out of the mold. In *c*, the dead, *empty* shell was buried in mud and *filled with the same*, and afterward the shell was removed

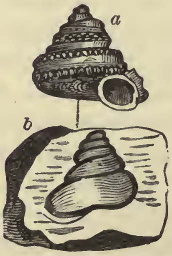


FIG. 119.—*a*, Natural form; *b*, cast of interior and mold of exterior.

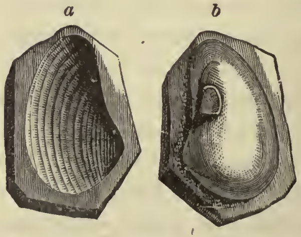


FIG. 120.—Trigonia longa, showing cast (*a*) of the exterior and (*b*) of the interior of the shell.

by solution, leaving an empty space corresponding to the thickness of the shell. In *d*, this hollow space was subsequently filled by deposit of soluble matters from percolating waters. Cases *c* and *d* are represented by Figs. 119 and 120.

Sometimes we have only the mold and cast of a small part of an organism, as, for example, impressions of the leaves of plants, or the footprints of animals walking on the mud when it was soft. These, however, are of great value, because they are very characteristic parts of plants and animals.

Finally, there are all grades of completeness of the process of replacement. In bones, shells, and teeth, sometimes only the organic matter is partly or wholly replaced. Sometimes, also, the mineral matter is replaced by other mineral matter.

Distribution of Fossil Species.

The kind of fossils which we find in the strata at any place will depend on three things : 1. On the *kind* of rock ; 2. On the *country ;* and, 3. On the *age* of the rock.

Kind of Rock.—We have already said (page 130) that at the present time different depths and bottoms are frequented by different marine species. Some live on sand-bottoms, some on mud-bottoms, and some on deep-sea ooze. The same was true in previous epochs, and therefore we ought to expect and we do find that, in the same country, and in strata of the same age, sandstones will contain different fossils from limestones ; the one being shore and the other open-sea deposit. Again, then as now, lake-deposits contained fresh-water animals, and estuary deposits land plants and animals ; and these are of course different from marine species, though they be of the same age and country.

The Country.—In rocks of the same age and same kind, but in different continents, we shall often find a great difference of species, for we find the same thing true of living species (page 118). But the geographical diversity of fossil species, as a general fact, is not so great as that of living species. Commencing with the earliest times, the geographical differences of species have increased more and more to the present time.

The Age.—The distribution of fossil species according to the age of the rocks is the main subject of Part III, or Historical Geology; but some general notions on this subject are necessary as a basis of classification of stratified rocks, and must therefore precede that part.

Successive Geological Faunas and Floras.—The fossil species found in rocks, even of the same kind and country, will depend largely on the *age* of the rocks. The whole earth has been inhabited at different times by entirely different species. All the animals and plants inhabiting the earth at one time are called the fauna and flora of that geological time. Thus we have a fauna and flora of Tertiary times, of Jurassic times, of Devonian times, etc.

Definition of Formation and Period.—When the strata are conformable, the change from one geological fauna to another is *gradual,* but a line of unconformity usually abruptly separates two faunas. A *formation,* therefore, is a series of conformable strata, in which the fossil species are either the same or change very gradually; and a *geological period* is the period during which such a formation has been laid down. There are two tests, therefore, of the limits of a geological formation and a geological period, viz., unconformity of the rock-system and great change in the species. Of these the latter is the more valuable.

Law of Gradual Approach to the Present.—It is a fundamental and very important fact that in the successive changes of geological species there is a steady approach to living forms, first in families, then in genera, and then in species. Species do not begin to be identical with the living species until the Tertiary period, and thence onward we have an *increasing percentage,* identical with the living.

Now, we determine that rocks belong to the *same time,* all over the earth, by the *general similarity* of the fossil species. We find difficulty in applying this rule only in the Tertiary, because then the geographical diversity is beginning to be so great as seriously to interfere with the general similarity. But just here we begin to use another principle, viz., the percentage of the fossil species still living in the immediate vicinity. Similar percentage indicates the same age—greater percentage less age, and less percentage greater age.* It is on these principles that is based the classification of stratified rocks.

SECTION II.—CLASSIFICATION OF STRATIFIED ROCKS.

Geology is a history. Stratified rocks are the leaves of an historical book. Evidently, then, the true basis of classification must be *relative age.* In classification, the geologist has two objects in view: 1. To arrange all the strata, from lowest to highest, in the order in which they were formed. 2. Then to separate them into groups and sub-groups for convenient treatment—i. e., 1. To arrange the leaves in the order in which they were written, so that the story they contain may be read intelligently. 2. To divide and subdivide into chapters and sections, determined by great events in the history. In a word, he must make first a *chronology,* and then divide into eras, ages, periods, etc.

Chronology; Order of Superposition.—It is evident, from the manner in which sediments are formed, that, if they have not been greatly disturbed, their *relative position indicates their relative ages*, the uppermost being of course the youngest. If, therefore, we have a natural section of strata (an exposed sea-cliff or cañon-side), either horizontal or regularly inclined, it is easy to make out the relative ages. But often the rocks are folded and crumpled, and pushed over beyond the vertical; they are broken and slipped, and a large part worn away by erosion; they are covered with soil and hidden from view; so that to make an ideal section showing their *real* relation is one of the hardest of geological problems. Nevertheless, if this were all, we might still hope for perfect success. But *all the strata are not represented in any one place*—usually only a fraction. Thus, in New York, and all the States westward as far as the Plains, only the older portion of the record is found; while in California we have mostly the later portion. In many places the record is still more fragmentary. The leaves of this book are scattered about—here, perhaps, nearly a whole volume; there, one or two chapters; and yonder, only a few leaves. The geologist must gather these and arrange them according to their paging; and then divide and subdivide them into volumes, chapters, etc. Therefore, although the order of superposition must, wherever it can be applied, take precedence of every other method, yet it must be supplemented by careful comparison of the rocks in different localities with one another. There are two means of comparison, viz., the *character of the rock* and the *character of the fossils*.

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* The teacher should consult the larger work, for a complete statement.

Comparison by Rock-Character.—This method is of little value except in contiguous localities. Sandstones of similar character belong to nearly all times, and are forming now. So, also, of clays and limestones. Coal was once considered characteristic of a particular age, but now is known to occur in strata of many ages. Chalk was once supposed to be characteristic of the Cretaceous, but is now known to be forming at present in deep seas. But since, both now and in former times, the same kind of deposits formed over wide areas, rocks of similar kind (for example, sandstones of similar grain and color), and especially a group of similar rocks, in *contiguous* localities, are probably of the same age. But in widely separated localities, as, for example, in different continents, we can not use this method. To conclude that rocks are of the same age, because they are of similar grain, color, or composition, would almost certainly lead us astray.

Comparison of Fossils.—This is the most universal and valuable means of comparison of rocks in all parts of the world. If we *find a general similarity of species*, we conclude that the rocks *belong to the same age*. But we must make due allowance—1. For difference of conditions of deposit, whether shore-deposit or deep-sea deposit, whether fresh-water or marine. 2. We must also make due allowance for geographical diversity. We must expect, in fossils of rocks in different continents, not absolute identity, but only *general similarity*. We shall find little difficulty in applying this, until we come to the Tertiary. But here we have another principle to help us, viz., the percentage of *living* invertebrates found in the rock. Vertebrate, and especially mammalian species, may be used in the Tertiary in much the same way as all species in the lower rocks.

Construction of Chronology.—By application of these methods, geologists in all countries, working together, have gradually made a nearly complete chronology. Breaks in one country are filled by strata in another. But a really complete chronology can not be expected until the whole surface of the earth has been studied, and perhaps not even then, for some missing links are probably concealed beneath the sea.

Divisions and Subdivisions.—The next task is to divide and subdivide the whole into primary and secondary groups—into volumes, chapters, etc., separated by great changes. As already explained (page 204), there

ERAS.	AGES.	PERIODS.	EPOCHS.
5. Psychozoic.	7. Age of Man.	Human.	Recent.
4. Cenozoic.	6. Age of Mammals.	Quaternary.	Terrace. Champlain. Glacial.
		Tertiary.	Pliocene. Miocene. Eocene.
3. Mesozoic.	*Secondary rocks.* 5. Age of Reptiles.	Cretaceous. Jurassic. Triassic.	
2. Paleozoic. Upper	*Carboniferous rocks.* 4. Age of Acrogens and Amphibians.	Permian. Carboniferous. Subcarboniferous.	
	Devonian rocks. 3. Age of Fishes.	Catskill. Chemung. Hamilton. Corniferous. Oriskany.	
Lower	*Silurian rocks.* 2. Age of Invertebrates.	Helderberg. Salina. Niagara. Trenton. Canadian.	
	Cambrian or primordial rocks.	Upper. Middle. Lower.	
1. Archæan or Archæozoic.	1. Archæan rocks.	Huronian. Laurentian.	

are two modes of determining the limits of the divisions of the rocks, and corresponding divisions of time, viz., by *unconformity of the rocks,* and by *change of the fossils.* These two usually occur together, because they are produced by the same cause, viz., change in physical geography and climate; but, if there be discordance between the two, then we follow the change in the fossils rather than unconformity of rocks. By means of the *most general unconformity and greatest change in fossil forms,* the primary divisions are established; and then, by less general unconformity and less important changes in organic forms, these are divided and subdivided. A generalized schedule of the divisions and subdivisions of the rocks and corresponding divisions of time which will be used in this work, is given on the preceding page.

CHAPTER III.

UNSTRATIFIED OR IGNEOUS ROCKS.

THESE differ wholly from the stratified rocks—1. By absence of true stratification, i. e., lamination by sorting of material. 2. By absence of fossils. 3. By a crystalline or else a glassy texture instead of an earthy texture. 4. By mode of occurrence, as explained below.

Origin.—All these characteristics are the result of their mode of origin. They have consolidated from a state of fusion or semi-fusion, and poured out from *below,* instead of deposited as sediments from *above.* Their original fused condition is shown by their crystalline or glassy texture, by their occurrence injected into fissures, or even tortuous cracks, and by their effects on the stratified rocks with which they come in contact.

Mode of Occurrence.—They occur in three main positions : 1. Underlying the stratified rocks and appearing on the surface in great masses, especially in mountain-

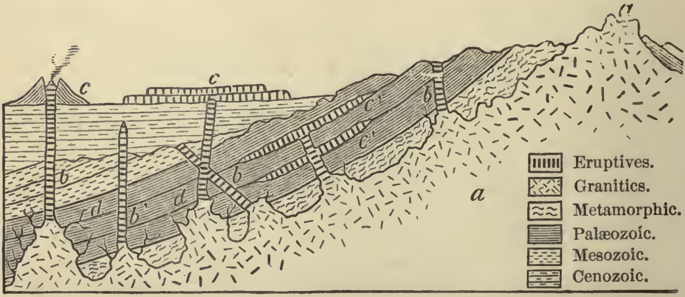

FIG. 121.—Ideal section of the earth's crust.

ous regions (*a*, Fig. 121). 2. In vertical sheets intersecting the stratified rocks or other igneous rocks, *b*. 3. In streams or sheets overlying the stratified, or else between the strata, *c c'*. 4. Sometimes as tortuous veins, *d d*, connected with the great underlying masses. All of these are connected with, and are extensions of, the great underlying masses.

Extent.—As thus defined, igneous rocks occupy but a small portion, certainly not more than one tenth, of the land-surface. But beneath the stratified rocks they are supposed to form the great mass of the earth.

Classification of Igneous Rocks.—Igneous rocks can not be classified, like sedimentaries, by relative age. They are best classified partly by texture and partly by mode of occurrence. They thus fall into two strongly contrasted groups, viz., *plutonics* and *volcanics*, or *granitics* and *true eruptives.* The rocks of the one group are very *coarse*-grained and wholly crystalline, of the other, finer-grained or even glassy. The one occurs only in great *masses*, either underlying the stratified rocks, or appearing on the surface over wide areas, especially in the axes of mountain-ranges; the other, in *sheets* injected among the strata, or as *streams* and *sheets* outpoured on the surface. The granitics have not usually been erupted at all, although they often form the reservoirs from which eruptions have taken place.

It is sometimes convenient to speak of an intermediate group—*trappean.* If so, then the three kinds correspond to the three positions mentioned above. The granitic (Fig. 121, *a*) occur *beneath;* the trappean, *b b*, injected *among;* the volcanic, *c c*, outpoured *upon*, the stratified rocks.

I.—THE MASSIVE OR GRANITIC GROUP.

The rocks of this group occur in great masses, not in sheets or streams. They are all very coarse-grained in texture, and have a speckled or mottled appearance, because composed of crystals of considerable size, and of different colors, aggregated together. The crystals of which they mainly consist are, quartz, feldspar, mica, and hornblende. In such a coarse, speckled rock, the bluish, glassy, transparent spots are quartz ; the opaque, whitish, or rose or greenish crystals, with striated surface, are feldspar ; the black spots are usually hornblende ; the mica may be known by its thin, scaly structure, sometimes pearly, sometimes black.

The whole group is called granitic, because granite is its best type. In popular language, indeed, all these rocks would be called granite, but science makes a difference. If the rock consists of quartz, feldspar, and mica, or else of these with hornblende, then it is *granite proper.* If it consists of feldspar and hornblende, or these with quartz, it is called *syenite.* If it consists of only quartz and feldspar, and the quartz be in bent plates, looking, on section, like Hebrew characters, it is called *pegmatite* (Fig. 122). The feldspar in all these is potash-feldspar, or *orthoclase.* *Diorite* is a dark, speckled rock of the same composition as syenite, except that the feldspar is a soda-lime feldspar or *plagioclase.* *Gabbro* and *diabase* are dark-greenish rocks similar to diorite, except that the hornblende is replaced by *augite* and *olivine.*[*]

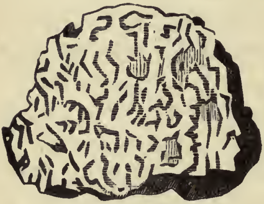

FIG. 122.—Graphic granite.

Mode of Occurrence.—The mode of occurrence of these rocks has been already explained. They *never* occur in *overflows.* They *rarely* or never occur in intruded *sheets* or *dikes.* They occur only in great *masses,* or sometimes in tortuous veins closely connected with the great masses, as if forced into cracks by heavy pressure (Fig. 121, *d*). Their coarsely crystalline texture and their mode of occurrence are well explained by supposing that they have cooled at *great depth* in *large masses,* and consequently *slowly.* When they appear at the surface, therefore, they have been exposed by extensive erosion.

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[*] The teacher *must* have a small collection of rocks and of minerals for illustration.

Two Sub-Groups.—All igneous rocks, whether plutonic or volcanic, are divisible into two sub-groups, *acidic* and *basic.* In the acidic, quartz and potash-feldspar (orthoclase) predominate; in the basic, hornblende or augite and soda-lime feldspar (plagioclase) predominate. The rocks of the former group are lighter colored and less dense; of the latter, are darker and heavier; but the two sub-groups run insensibly into each other. Among the granitics, granite is the best type of the acidics; and diorite, and especially gabbro or diabase, of the *basics.*

Intermediate Series.

Between the true plutonics and true volcanics there is an intermediate series, called *trappean* or *intrusives.* If the plutonics occur in *masses beneath,* the volcanics in outpoured streams and sheets *upon,* these occur in sheets intruded *among,* the strata, especially of the older rocks. They are finer-grained than the plutonics and more crystalline than volcanics. The reason, apparently, is that they have cooled more rapidly than the former, and less rapidly than the latter. These are also divisible into acidics and basics. Among the acidics would come *felsite* and *porphyry,* and, among basics, diorite and diabase, for these occur both massive and intrusive.

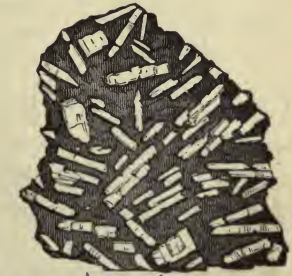

FIG. 123.—A piece of porphyry (after Lyell).

Diorite and diabase have already been described. It is only necessary to say that, when occurring intrusive, they are finer-grained than the massive varieties. Felsite is a fine-grained, light-grayish rock, consisting essentially of orthoclase and quartz. Porphyry is a rock consisting of fine-grained feldspathic paste, with disseminated large crystals of feldspar (Fig. 123). But any rock is said to be porphyritic if it consists of fine-grained paste with large crystals of any kind disseminated.

II.—VOLCANICS, OR TRUE ERUPTIVES.

The rocks of this group are distinguished from those of the other, both by texture and mode of occurrence. By texture they are not only finer-grained (micro-crystalline), but there is always more or less of uncrystalline or glassy base or cement, showing that the fused mass has cooled *too quickly* to allow complete crystallization. Often, also, as already explained under volcanoes (page 139), these rocks are in a wholly glassy and even in a scoriaceous and tufaceous condition. The principal rocks of this group are given in the accompanying table.

VOLCANIC ROCKS.		
ACIDIC.		BASIC.
Stony.	Rhyolite.	Basalt.
	Trachyte.	Dolerite.
	Phonolite.	Andesite.
Glassy.	Obsidian.	Tachylite.
	Pumice.	Black scoriæ.

Trachyte may be taken as a type of the acidics. It is a light-colored rock, with a rough feel (hence the name), consisting essentially of orthoclase with more or less quartz. When the quartz-grains are conspicuous, it becomes *rhyolite*. *Phonolite* is a dense variety, of light-grayish color, which splits into slabs in weathering, and rings under the hammer almost like metal (hence the name). *Obsidian* and *pumice* are glassy and scoriaceous varieties of trachyte.

Basalt is the type of the basics. It is a very dark, almost black, heavy rock, scarcely visibly grained to the naked eye, and breaking with conchoidal fracture. It consists of plagioclase with augite, olivine, and magnetite. *Dolerite* has a similar composition, but more distinctly crystalline texture, and therefore dark-grayish color. *Tachylite* is the glassy variety, which, if vesicular, becomes black scoria.

The following table is a condensed statement of the composition of the principal kinds of rocks numbered above. The sign × × indicates crystals.

IGNEOUS ROCKS.

		ACIDIC.			BASIC.	
II. VOLCANIC ROCKS.	Occurring in overflows.	*Rhyolite.* Vitreous base. + × × of Quartz, Orthoclase (sanidin).	*Trachyte.* Vitreous base. + × × of Orthoclase (sanidin).	*Phonolite.* Vitreous base. + × × of Sanidin, Nephelin.	*Andesite.* Vitreous base. + × × of Plagioclase, Augite, or Hornblende.	*Basalt.* Vitreous base. + × × of Plagioclase, Augite, Olivine.
I. PLUTONIC ROCKS.	Occurring in intrusions.	*Quartz-porphyry.* Micro × × ground-mass. + × × of Orthoclase, Quartz.		*Felsite.* Micro × × of Orthoclase, Quartz.	*Diorite.* See below.	*Diabase.* See below.
	Occurring massive.	*Granite.* × × of Quartz, Orthoclase, Mica.		*Syenite.* × × of Orthoclase, Hornblende.	*Diorite.* × × of Plagioclase, Hornblende.	*Diabase.* × × of Plagioclase. Augite.

Two Modes of Eruption.—There are two modes of eruption. In the one, the fused mass comes up through chimneys, and flows off in streams (or ejected as cinders and ashes) ; in the other, it comes up through great fissures often hundreds of miles long, and spreads as extensive sheets. In the one the erupted matters accumulate about the vent as a cone; in the other they form great lava-fields, or else may be forced between the strata and never come to the surface at all. In the one the *force* of ejection is probably the elastic force of vapors, as explained under volcanoes; in the other the force is more obscure, but probably of the same nature as that which *forms mountains.* The two kinds may be called *crater-eruptions* and *fissure-eruptions.* At present only the former kind seems to exist; and therefore in Part I, while treating of causes now in operation, we treated only of this mode. But in studying erupted materials of *all periods,* it is plain that by far the larger quantity have come up in the second way.

Modes of Occurrence.—Leaving out of view those modes of occurrence already described under volcanoes, viz., chimney-cones with radiating dikes and lava-streams, the principal modes of occurrence of eruptive rocks are: 1. *Dikes.* 2. *Overflow-sheets.* 3. *Intercalary beds.*

1. **Dikes.**—Dikes are vertical sheets filling great fissures in stratified or other igneous rocks. They are the most common of all modes of occurrence of eruptives and intrusives. In all mountain-regions they are found in great numbers. In width they vary from a few feet to hundreds of feet, and may often be traced outcropping over the surface fifty to one hundred miles. But since rocks are usually covered with soil, they are not always visible at once, but must be looked for wherever the rock is exposed, especially in stream-beds.

It is evident that fused matter coming to the surface must overflow, and therefore dikes thus outcropping on the surface are either the exposed roots of former overflows which have been removed by erosion, or else are the fillings of fissures which never reached the surface at all (Fig. 121, *b'*). In either case, an outcropping dike is the sign of great erosion. If, therefore, the dike is harder than the country-rock through which it breaks, it will stand above the surface and look like a low, ruined wall (Fig. 124, *a*). If, on the contrary, the igneous rock yield more easily to erosion than the country-rock, then it may be traced as a shallow, half-filled ditch (Fig. 124, *b*).

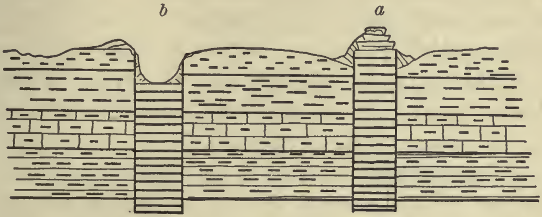

Fig. 124.—Dikes.

Effect of Dikes on Stratified Rocks.—On both sides of a dike the bounding walls of stratified rock are always changed by the intense heat of the fused matter. Sandstones are changed into a rock resembling gneiss (page 225), clays are baked into porcelain jaspers, limestones are changed into crystalline marbles, coal-seams into anthracite and sometimes into coke. In all cases the fossils, if any, are more or less completely destroyed. These *metamorphic* changes usually extend only a few feet or yards from the place of contact.

2. **Overflows.**—This is the next most common form of occurrence. The liquid matter has come up through great fissures, such as are made by crust-movements, and spread on the surface as extensive sheets. Often sheet after sheet

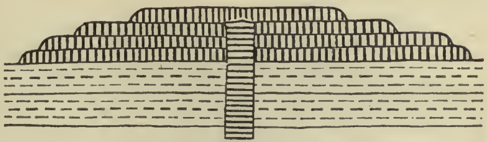

Fig. 125.—Lava sheets.

is outpoured, one on another, until masses 2,000 to 3,000 feet thick are piled up (Fig. 125).

The *extent* and *thickness* of some of these lava-floods are almost incredible. The great lava-flood of the Northwest covers the whole of northern California, northwestern Nevada, and a great part of Oregon, Washington, and Idaho, and extends far into Montana and British Columbia. Its area is supposed to be 150,000 square miles, and its thickness, where cut through by the Columbia River, is at least 3,000 feet. There are about a dozen extinct volcanoes dotted, at wide intervals, over this vast area. It seems certain that the lava came up through fissures in the Cascade and Blue Mountains, and spread as sheets which covered the whole intervening space. Afterward eruptive activity continued, in a more feeble form as volcanoes, almost to the present time. The great Deccan lava-field, described by the geologists of India, covers an area of 200,000 square miles, and is in places 6,000 feet thick, and there is no evidence of any crater-eruptions at all.

These very extensive sheets are usually basalt. In some parts of the Utah and Nevada Basin region, however, rhyolitic and trachytic lavas are found 7,000 feet thick, but these are far less extensive. As a general rule, the *basic* lavas, like basalt, were very liquid (superfused), and spread out in thin sheets, while the acidic lavas, like trachyte, have been stiffly viscous (semi-fused), and were squeezed out *dome-shaped.*

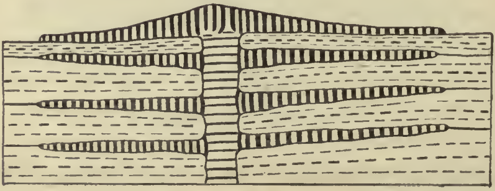

Fig. 126.—Intercalary beds.

3. **Intercalary Beds.**—Often sheets are found between the strata, sometimes repeated many times. In such cases they may have been poured out on the bed of the sea or lake, and covered with sediment; or they may have broken through the strata for a certain distance, and then spread between the separated strata (Fig. 126). Both of these cases occur. If the strata both above and below the sheet are changed by heat, then it has been forced between; but if only the underlying stratum is changed, then it has been outpoured on the bed of the sea or lake, and covered with sediment.

Age of Eruptives.—Where two dikes or streams meet, their *relative* ages may be known. In case of successive streams, that which covers is of course the later. If one dike intersects another (Fig. 127), the intersecting dike, *a*, is the younger. The *absolute* age, i. e., the geological period when the eruption took place, can be determined only by the age of the associated stratified rocks. If igneous rocks break through, or are outpoured upon,

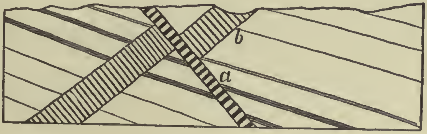

FIG. 127.

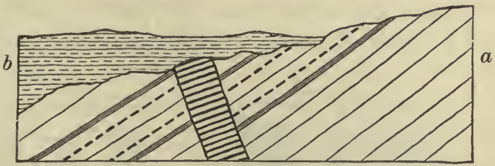

FIG. 128.

or forced between layers of stratified rocks, then the igneous rock must be younger; but if intercalary beds are the result of outpouring on the bed of the sea, and covering it with sediment, then the igneous and the stratified rocks are *contemporaneous.* Finally, if dikes outcropping on the surface are covered with other strata through which they do not break (Fig. 128), then they are younger than the lower series, *a,* and older than the upper, *b.*

Some Structures common to Many Eruptives.

Columnar Structure.—Many eruptive rocks, especially of the more basic kinds, seem to be wholly made up of regular prismatic columns (Fig. 129). This remarkable structure is most common and perfect in basalt, and is therefore often called basaltic structure. The columns vary in size from a few inches to several feet in diameter, and in length from a few feet to one hundred feet; the number of sides from three to seven, more com-

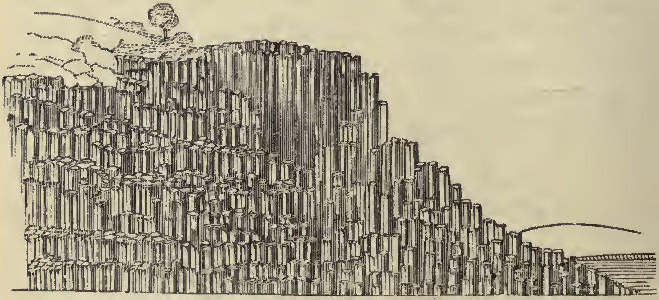

Fig. 129.—Columnar basalt, New South Wales (Dana).

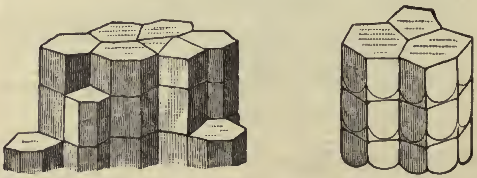

Fig. 130.—Basaltic columns (after Geikie).

monly five or six. The columns are not usually continuous, but short-jointed, like a vertebral column (Fig. 130).

The *position* of the columns is usually perpendicular to the cooling surface. Thus, in vertical sheets, like dikes, they are horizontal, and an outcropping dike often presents the appearance of a pile of corded wood (Fig. 131).

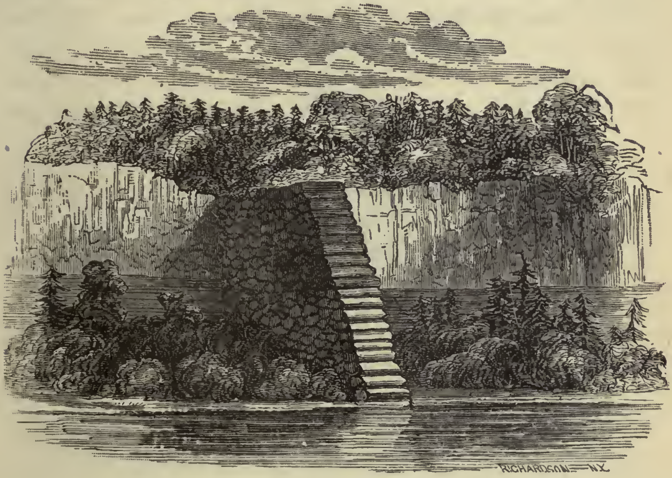
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FIG. 131.—Columnar dike, Lake Superior. (After Owen.)

In overflow-sheets the columns are vertical (Fig. 129), and at the base of a cliff of such rocks are found piles of separated and disjointed columns.

The *cause* of this structure is shrinkage by *cooling.* Many substances shrink by *drying,* and break into prismatic columns. Mud thus forms polygonal prisms by sun-cracks. Wet starch, poured into boxes and drying, breaks into prismatic pencils. In the case of lava, the shrinkage is by *cooling,* instead of drying, and the prisms are far more regular.

Examples of this structure are found in every country, and give rise to many remarkable scenes. In *Europe,* the

Giant's Causeway in Ireland, and Fingal's Cave on the Island of Staffa, are good examples. The Giant's Causeway is a sea-cliff of columnar basalt, consisting of many layers, with softer material between, and the whole resting on stratified rock. By the action of the sea and air the separated and disjointed columns are undermined and fall to the base of the cliff. In *this country,* the Palisades of the Hudson River, and Mounts Tom and Holyoke in the Connecticut River Valley, are good examples. Fine examples are found also in the trap of Lake Superior (Fig. 132). But the finest in this country are the

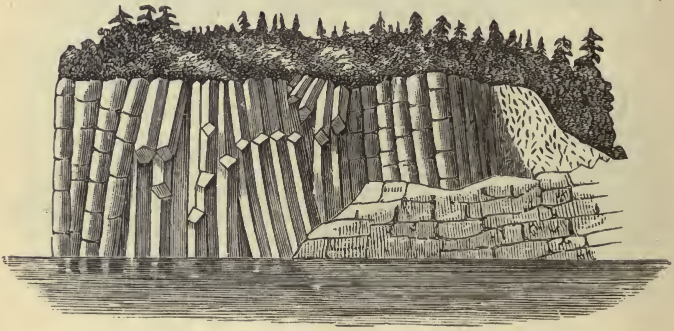

Fig. 132.—Basaltic columns on sedimentary rock, Lake Superior. (After Owen.)

basaltic cliffs of Columbia and Des Chutes Rivers in Oregon. On the Des Chutes River at least thirty lava-layers may be counted, one above another, each entirely composed of vertical columns.

Volcanic Conglomerate and Breccia.—If a lava-stream runs down a stream-bed or a shingly beach, it gathers up the pebbles and forms with them a conglomerate differing from aqueous conglomerate in the fact that the uniting paste is igneous instead of sedimentary. So, also, a lava-stream may gather up rubble and form a volcanic breccia differing in the same way from sedimentary breccia.

Amygdaloid.—The upper part of a lava-stream is vesicular, or full of air-bubbles. If such a stream be covered by another stream, percolating waters, charged with silica and carbonate of lime gathered from the lava, will fill up the empty spaces with these materials. If the rock be broken or weathered, these amygdules fall out. They *look* somewhat like *pebbles*, and the rock (Fig. 133) might be mistaken for conglomerate, but is formed in an entirely different way. The filling of the cavities takes place slowly, layer within layer, and the layers are often of different colors. It is in this way that are formed the most exquisite agate and carnelian nodules.

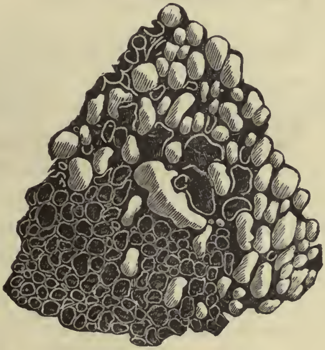

FIG. 133.—Amygdaloid.

Tufas.—When volcanic materials disintegrate, and are then moved and deposited in water, they form *tufas*. Sometimes the fragments may be larger and the mass may simulate volcanic breccia. It is, however, an *aqueous* breccia of *volcanic* rock. Such are sometimes called volcanic *agglomerates*.

CHAPTER IV.

METAMORPHIC ROCKS.

We have now finished both the stratified and the unstratified rocks, but there is yet an intermediate series which must be described. These are stratified like the stratified rocks, but crystalline in texture, and usually destitute of fossils, like the igneous rocks. They are supposed to have been formed from sediments like stratified rocks, but have been subsequently changed by heat and other agencies. They are therefore called *metamorphic* rocks. They may be traced by gradations, on the one hand, into stratified, and, on the other, into igneous rocks.

Extent and Thickness.—They cover large areas, especially among the oldest rocks and along axes of great mountain-chains. The whole of Labrador, the larger portion of Canada, the whole eastern slope of the Appalachian, and also the axes of the Colorado and Sierra, consist of them. In Canada they are supposed to be 40,000 to 50,000 feet thick and very much crumpled. Metamorphism is nearly always associated with great thickness and crumpling.

Age.—The oldest rocks are all metamorphic. Hence many regard it as a *sign of age.* But it is probably more correct to say that metamorphism is found in rocks of all ages if only they be very thick and very much crumpled; but, since great thickness and complex crumplings are most common in the oldest rocks, so also is metamorphism.

Kinds.—The adjoining table shows the principal kinds: *Gneiss* is a rock having much the appearance and mineral composition of granite—i. e., quartz, feldspar, mica, and hornblende—differing only in a *bedded structure.* In many places, as, for example, on Manhattan Island, gneiss can be traced by insensible gradations into granite. *Schists* are rocks having a *fissile* structure through the abundant presence of scales of some kind. In mica-schist they are mica; in the other schists they are chlorite, or talc, or hornblende.

clay Chi[illegible]

Gneiss.
Mica-schist.
Chlorite-schist.
Talcose-schist.
Hornblende-schist.
Clay-slate.
Quartzite.
Marble.
Serpentine.

Quartzite and Marble are both white, crystalline, or granular rocks, looking like loaf-sugar; but in the one case the granules are quartz, in the other, lime-carbonate. *Serpentine* is a greenish rock, having usually a schistose structure and a greasy feel like talc. It contains a notable quantity of magnesia.

Origin of these Kinds.—Metamorphic rocks are probably changed sandstones, limestones, and clays, and mixtures of these. The infinite variety which we find is the result partly of the original kind and partly of the degree of change. For example, sandstones and limestones are often perfectly pure. Now, a metamorphic pure sandstone is quartzite, and a metamorphic pure limestone is marble. But clays are nearly always *impure,* being mixed with sand and lime and iron and other bases. A moderately pure clay with a little sand by metamorphosis makes *gneiss* or *mica-schist.* If it contains much iron, it makes a hornblende-schist; if magnesia, talcose-schist or serpentine. Serpentine is, however, often a changed eruptive rock.

Cause of Metamorphism.

There are two kinds of metamorphism which must be distinguished, viz., *local* or *contact* metamorphism, and *regional* metamorphism. The former is produced by direct contact with fused matter, as in dikes or intercalary beds (page 217). There can be no doubt as to the cause in this case. It is *intense heat.* But the effect of the heat extends but a little way from the plane of contact. In regional metamorphism, on the contrary, the change is universal over hundreds of thousands of square miles and thousands of feet of thickness. In these cases there is no evidence of intense heat in every part; the heat was probably very moderate. It is of this kind that we now wish to explain the cause.

The Agents of regional metamorphism are—1. Heat; 2. Water; 3. Alkali; 4. Pressure; 5. Crushing.

To produce metamorphism by *heat alone,* i. e., *dry* heat, would require a temperature of 2,500° to 3,000°, but in the presence of *water* a very moderate heat will change rocks. At 400° Fahr. (= 205° C.), incipient change commences; and at 800° Fahr., complete hydrothermal fusion takes place. If any *alkaline carbonate* be present in the water, these effects occur at still lower temperature. The *quantity* of water necessary is only ten to fifteen per cent.; in other words, the *included water of sediments* is amply sufficient. *Pressure* is necessary, because it is impossible to have even such moderate heat in the presence of water, unless the whole be under pressure.

Application.—Suppose, then, we have sediments accumulating along a shore-line, or at the mouth of a river until a thickness of 10,000, 20,000, or 40,000 feet is reached. It is evident that the isogeotherms (interior isotherms) would rise, and the lower portion of the sediments with their included waters would be invaded by the interior heat of the earth (Fig. 134). At the rate of

100° increase per mile (page 132), the lower portion of the sediments 20,000 feet thick would be 400° + 60° (mean surface temperature) = 460°, and 40,000 feet of the sediments would be at the bottom 860°. Now, we actually have strata 20,000 and 40,000 and even more feet thick. The lower portions of such strata must be completely metamorphic. The figure (Fig. 134) shows how the process takes place.

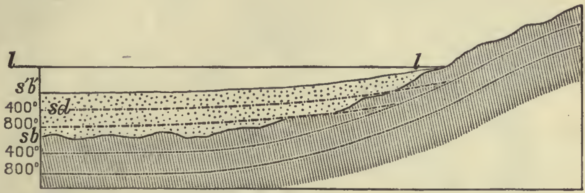

FIG. 134.—*sb*, original sea-bottom ; *s'b'*, sea-bottom after sediments, *sd*, have accumulated ; ...., isogeotherms of 800° and 400° ; — · — · —, same after accumulation of sediments.

Crushing.—Pressure alone is a *condition,* but not a *cause* of heat. But pressure producing *motion,* or *crushing, crumpling,* is an *active cause* of heat. Now, we usually find metamorphism associated with most complex crumpling of strata. The heat must have been increased also by this cause.

Even igneous rocks, by pressure, mashing, and shearing, may be made to assume the appearance of metamorphic stratified. Many schists, especially gneisses, are formed in this way.

CHAPTER V.

STRUCTURES COMMON TO ALL ROCKS.

We have now given a brief account of all the different kinds of rocks. But there are still some structures which are found in all kinds of rocks, and which could not be described until these kinds had been defined. These are: 1. *Joints;* 2. *Great fissures;* and, 3. *Mineral veins. Mountain-chains,* as involving all kinds of rocks and all kinds of structure—in fact, as summing up all the principles of dynamical and structural geology—we must take last of all.

SECTION I.—JOINTS AND FISSURES.

Joints.

We have already alluded to joints in stratified rocks (page 179), but without describing them, because not characteristic of these rocks. All rocks—sedimentary, igneous, and metamorphic—are divided by cracks in different directions into separable blocks of various sizes and shapes. These cracks are called *joints.* In stratified rocks, one of the division-planes is between the strata, and the other two nearly at right angles to this. The shape and size of the blocks differ in different kinds of rocks. For example, in sandstone the blocks are usually very large and roughly prismatic; in limestone, they are usually very regularly cubic (Fig. 135); in shale, oblong rhomboidal; in slate, small and sharply rhombic; in granite, sometimes large and roughly cubic, sometimes scaling in concentric shells, producing domes; in eruptives, of many shapes, rough cubic, ball-like, regular columnar, tilelike.

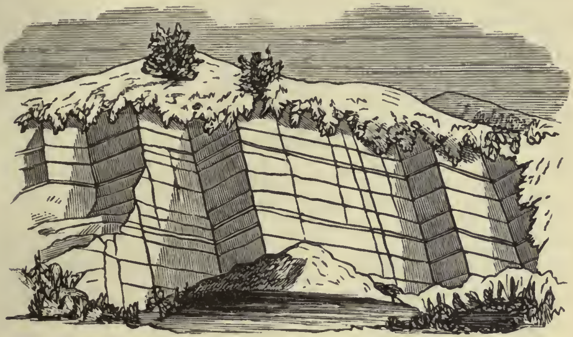

FIG. 135.—Regular jointing of limestone.

For this reason a cliff, especially of stratified rock, looks like a wall of titanic masonry without mortar.

Cause.—These cracks are supposed to have been formed by the shrinkage of the rocks; in stratified rocks, in consolidating from sediments; in igneous and metamorphic rocks, in cooling from a state of fusion or semi-fusion. In stratified rocks they are usually confined to the stratum, though some larger joints (master-joints) run through several strata. They are mentioned mainly that the student should not confound them with other kinds of structure.

Great Fissures.

Joints are probably shrinkage-cracks. Fissures are fractures by crust-movements. Joints are cracks of the individual strata; fissures are fractures of the earth's crust, extending through many formations, and continuing for many miles.

Cause.—We shall see hereafter that the earth's crust is subjected to a powerful horizontal pressure, by which it is sometimes mashed together, sometimes thrown into arches and hollows. Such bendings of the crust produce enormous fractures parallel to the axis of the bending, and parallel to mountain-ranges, since mountain-ranges are produced in this way. Sometimes there is a system at right angles to the main system, or in the direction of the cross-valleys of mountains.

The characteristics, therefore, of great fissures are—1. Their occurrence in systems, usually parallel to the axis of elevation. 2. Their length, often extending for hundreds of miles. 3. Their depth, sometimes breaking through miles of thickness of rock. When filled at the moment of formation with fused matter from below, they form *dikes;* and all great dikes and igneous overflows have been through such fissures. But if not filled *at once* with *fused* matter, but *slowly* afterward with *mineral* matter, they form the great *fissure-veins*. Whether they are filled at once with fused matter, or afterward slowly with mineral matter, or remain empty, the walls do not usually remain in their original position, but nearly always *slip* one on the other up or down. Such a displacement of the crust on the two sides of a fissure is called a *fault*. We have already treated of dikes; we shall hereafter take up mineral *veins*. We must now speak briefly of faults.

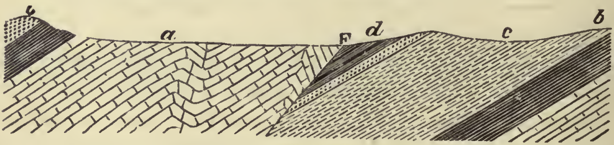

FIG. 136.—Fault in Southwest Virginia: *a*, silurian: *d*, carboniferous. (After Lesley.)

Faults.

As already explained, these are displacements of fissure-walls. They take place on an immense scale. Lesley mentions a fissure in Pennsylvania in which the vertical displacement is 20,000 feet, and may be traced for twenty miles. Rogers describes one in southern Virginia in which the displacement is 8,000 feet, and may be traced for eighty miles (Fig. 136).

According to Powell, there is on the north side of the Uintah Mountains a vertical slip of 20,000 feet. All along the eastern side of the Sierra there is a slip of not less than 15,000 to 20,000 feet; and King thinks the slip on the west side of the Wahsatch is even 40,000 feet. But they are developed on perhaps the grandest scale in the Colorado plateau region. This high plateau is traversed by a system of north and south fissures, 100 to 200 miles long, by which the arched earth-crust is broken into huge blocks, and these have settled to different levels, some 5,000 to 12,000 feet below others, and thus give rise to a wonderful system of north and south cliffs (Fig. 137).

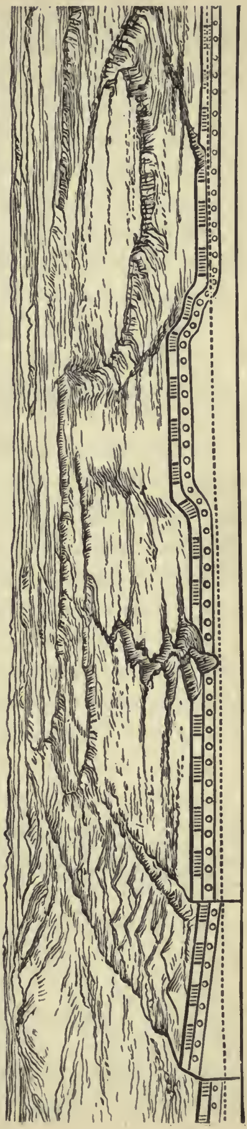

Fig. 137.—Faults and monoclinal folds of plateau region; section 90 miles long. (After Powell.)

If such a slip takes place suddenly, then at first there must have been a cliff as great as the slip. The same would be true even with gradual slipping, if there were no erosion. But both the slipping and the erosion have probably been going on slowly all the time, and whether there be a cliff or not, depends on the age of the fracture and the relative rate of slipping and erosion. In many of the faults of the plateau and basin region, the cliff still exists (though not as great as the displacement), because of the comparative recency of the fractures and dryness of the climate. The great Sierra fault is marked by a steep slope of 8,000 to 10,000 feet to the east, that of the Wahsatch of 8,000 feet to the west. But in the Uintah fault, and in all the faults of the Appalachian region, there is actually no surface-sign of the fault (Fig. 136). We may stand astride of the fissure.

Two Kinds of Faults.—Faults are of two kinds, according to the direction of the slip. Fissures are nearly always *inclined,* and therefore have what miners call a *foot* (lower) wall and a *hanging* (upper) wall. More commonly the hanging wall *drops* down. These are *normal* faults. But sometimes the hanging wall is *pushed* up over the foot wall. These are called *reverse* faults. In normal faults the broken parts are readjusted by gravity (settling); in reverse faults the broken parts are *crushed* together and *forced* to slide. The upper wall over the lower (Fig. 136) is a reverse fault. Fig. 136 shows only normal faults.

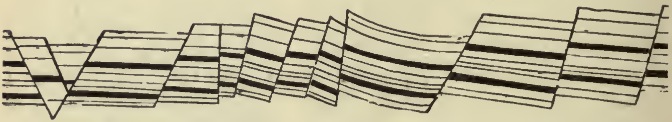

FIG. 138.—Section across Yarrow Colliery, showing the law of faults. (After De la Beche.)

Law of Slip.—In cases of displacement of strata it becomes often a matter of great importance, not only to the field geologist but also to the practical miner, to know which side has gone up or down; for valuable beds of coal or veins of metal are thus displaced, and it is important to know which way they went. Now, normal faults are far the more common, and therefore a very *general* though not universal rule in such cases is this: In case of inclined fissures, the *foot-wall* or lower side has gone up, or the hanging wall or upper side has dropped down. Or, it may be otherwise expressed, thus: "The dip or *hade* (slope) of the fissure is toward the down-throw." In Fig. 138, which represents an actual section, the rule is followed in every fissure. The exceptions to this rule (Fig. 136) are found only in the strongly folded rocks of mountain-regions.

SECTION II.—MINERAL VEINS.

Let any one examine rocks, especially metamorphic rocks, in mountain-regions, and he will see that they are marked with seams and scars running in all directions, as if they had been crushed and broken and again mended; as indeed they were. Now, all such markings and seamings, whatever be their nature and origin, are often called by the general name of veins. Thus, beds of coal, or gypsum, or salt, on the one hand, and the fillings of fissures by fused matter, on the other, are sometimes called *veins*. It is evident that no scientific progress can be made so long as things so different are confounded under the same name.

Definition.—Putting aside, then, all beds formed as sediments at the bottom of water, such as coal, gypsum, etc., and all fillings of fissures by fused matter, such as dikes, etc., veins may be defined as (usually) the fillings of fissures or cracks by slow deposits from solution in percolating waters, of materials leached from the surrounding or underlying rocks. Since the deposit takes place from *solution,* the materials of veins are in a purer and more sparry condition than they exist in the rocks.

It is evident that, as thus defined, veins must vary greatly in appearance. Sometimes they are fine lines, the fillings of small cracks produced by rock-crushing. Sometimes they are the fillings of larger joints. Sometimes they are the fillings of great fissures breaking through the earth-crust. It is these last which are far the most important; and it is only on these, therefore, that we shall dwell.

Fissure-Veins.—As these are the fillings of those great fissures which are formed by crust-movements, they are of great extent. The fillings of such fissures at once with fused matters are called dikes (page 216); the fillings by slow deposit of mineral matter are *fissure-veins.* These veins, therefore, like fissures (page 229), of which they are the fillings, are often many miles in extent, many feet in width, and of unknown but certainly many thousand feet in depth. Like fissures, they occur in systems, parallel to each other and to the axis of elevation of the mountain where they occur. Between the vein and the wall-rock on either side there commonly exists a layer of clay called the *selvage.* It is very characteristic of true fissure-veins, and probably produced by the solvent effect on the wall-rock of water circulating between the vein and the wall.

Metalliferous Veins.—Metals may occur in *beds,* for example, iron (page 299), or filling cavities of any kind in rocks, as sometimes lead. But they most commonly occur in veins, especially fissure-veins. The further description of fissure-veins is best undertaken, therefore, under this head.

Contents.—We must not imagine that metalliferous veins are filled with metals. The fillings of fissures are of two kinds, viz., the *vein-stuff,* vein rock, gangue, or matrix (as it is variously called), and the metallic ore. By far the larger portion is usually vein-stuff ; and through this is disseminated the metallic ore in granules, strings, or larger masses (Fig. 140, *c*), or sometimes in a central sheet (Figs. 139, 141), as if deposited last of all. The principal *kinds* of vein-stuffs are silica, carbonates of lime, iron and baryta, sulphate of baryta, and fluoride of calcium (fluor-spar). Often, however, many kinds of minerals are aggregated into a veritable *vein-rock*. The most common of all is silica, in the form of quartz. Next comes lime-carbonate. The metals sometimes occur free (M), as, for example, always gold and platinum, often silver, and sometimes copper and mercury. But more commonly they occur as metallic sulphides (MS), carbonates (MCO_3), and oxides (MO). By far the most common form is sulphides. These facts are given in the schedule. The most abundant kinds are marked with a +.

VEIN-STUFF.	ORE.
+ + SiO_2	+ + MS
+ $CaCO_3$	+ MCO_3
F^2CO_3	MO
$BaCO_3$	M
$BaSO_4$	
CaFl	

Structure.—Veins have nearly always a more or less banded structure, as if the materials were deposited in successive layers, on the two sides alike. Sometimes the successive layers are of the same material, but of different colors (Figs. 139, *bb*, 140, *aa*); sometimes of different ma-

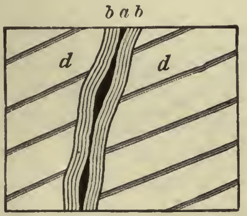

FIG. 139.—*a*, central sheet of ore ; *bb*, agate ; *d*, wall-rock.

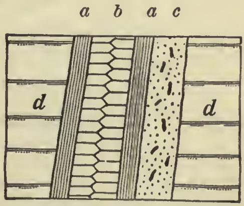

FIG. 140.—*aa*, agate ; *b*, quartz ; *c*, copper-bearing lode ; *d*, wall-rock.

terial (Fig. 141). Sometimes the bands are beautifully regular and distinct, like agate (Figs. 139, 140); sometimes on a larger scale, and irregular. Very often we find several corresponding layers of agate on the two sides, and the center filled with combs of quartz-crystals with interlocking teeth (Fig. 140, *b*).

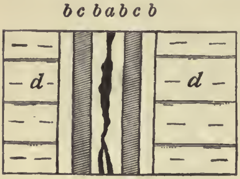

Fig. 141.—*a*, galena; *bb*, baryta; *cc*, fluor-spar; *d*, wall.

Irregularities.—Small veins, the fillings of small cracks, are extremely irregular, running in all directions, and intersecting each other in every conceivable way. Great fissure-veins are far more regular. But even these are more or less irregular, partly from the irregularity of the original fissure and partly from subsequent movements. Perhaps the most important of these is displacements by fissures or other veins, as explained below.

Age of Veins.—Often in the same locality we find two or more systems of veins, formed at different times, crossing each other. In such cases, as in dikes, the fissure or vein which cuts through the other (Fig. 142, *a*) is of course the younger. The absolute age, i. e., the geological period in which the fissure was made, can be known only by the age of the strata through which it breaks.

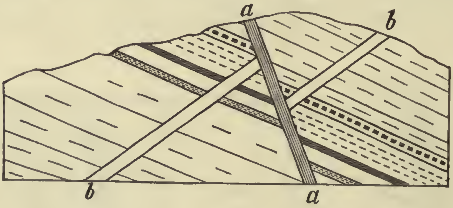

Fig. 142.

Recovery of Lost Veins.—Suppose *b* (Fig. 142) is a valuable vein, and we work down until we strike *a*. The vein is here lost by slips ; which way shall we go to recover it ? Remember the rule already given on page 233 : "The slope or dip or '*hade*' of the *displacing* fissure (here *a*) is toward the down-throw." This rule is not invariable, but very general.

Surface-Changes.—We must not imagine that metalliferous veins outcrop on the surface in the form we have described. If they contain no metal, veins may indeed appear unchanged on the surface. Quartz-veins may, for example, be often traced over hillsides by strewed fragments of white quartz. But metalliferous veins are usually so greatly changed on the surface that, without much experience, we would not recognize them at all. Precisely as rocks are usually concealed by soil resulting from surface-decomposition, so veins are concealed by surface-changes. To the experienced eye these surface-changes become surface-*signs,* and are therefore of the greatest practical importance. These surface-signs are far too complex and various to be explained here. We only mention them to guard the pupil against supposing that it is easy to see what we have described above, and to stimulate him to observe for himself.

Origin of Mineral Veins.—This is a difficult and obscure subject, but the following propositions are probably true : 1. Veins have been formed by deposit of mineral matters from solutions in percolating or subterranean waters. 2. The movement of the subterranean waters may have been in any direction, but mostly *up-coming.* 3. The waters may have been at any temperature, but mostly *hot.* 4. The water-ways may have been of any kind, but the openest water-ways—the highways of ascending waters—are *open fissures.* 5. The waters have been usually, though perhaps not always, *alkaline,* i. e., containing *alkaline carbonates* or *alkaline sulphides,* or both.

SECTION III.—MOUNTAINS: THEIR ORIGIN AND STRUCTURE.

Mountains are the glory of the earth—the culminating points of scenic grandeur and beauty. But few perceive that they are so only because they are also the culminating points of all geological agencies. This is but one illustration of the general truth, that there is an indissoluble and necessary connection between truth and beauty, between science and fine art. It is evident, then, that the study of mountains is the key to dynamical and structural geology.

The difficulty which meets us at the threshold of this subject is the loose use of the term *mountain*. The term is used to express every conspicuous elevation above the general level, whatever be its extent, and in whatever way it may have been formed. Thus an isolated eminence produced by circum-erosion, or a peak formed by volcanic ejection, a ridge between two stream-gorges, a great bulge produced by the folding of the earth's crust, or a series of such foldings parallel to each other in the same general region—are all called by the same name, mountain. Qualifying terms are indeed often used, such as mountain-*peak*, mountain-*ridge*, mountain-*range*, etc., but these also are used loosely and interchangeably. It is necessary, therefore, first of all, to *define* our *terms*.

Definitions.—A mountain-*chain*, or, better, **mountain-system**, is an assemblage of ranges parallel to each other in the same general region, but usually formed at different times (*polygenetic*). All the great mountain-chains of the world are of this nature. For example: The Appalachian system consists of the Blue Ridge, the Alleghany, and the Cumberland ranges. The Rocky Mountain system, or North American Cordilleras, consists of the Colorado range, the Park range, the Wahsatch, the Sierra, the Coast ranges, and many others. So the Alps, the Himalayas, and the Andes consist also of several parallel ranges.

A **mountain-range** is one of these great components, *formed at one time—by one earth-effort* (*monogenetic*), though the effort may have continued through a great period of time. The Colorado, the Uintah, the Wahsatch, the Sierra, and the Coast ranges are good examples. The Blue Ridge and the Alleghany ranges are also good examples.

A **mountain-ridge** is a subdivision, again, of a range, produced usually by *erosion,* although sometimes also by foldings of strata. *Mountain-peaks* are serrations of the crest of a range or a ridge, either by erosion or by volcanic ejections.

Mountain-systems are *separated* by great interior *continental basins ;* mountain-ranges by *great valleys ;* mountain ridges and peaks by narrow valleys or *gorges.*

Such is the simplest view of the form of mountains ; but sometimes a mountain-range seems to be composed of an inextricable tangle of ridges running in all directions.

Now, it is evident that any scientific discussion of the origin and structure of mountains must be essentially that of the origin and structure of *ranges ;* for, on the one hand, a mountain-system is a mere adding of range to range, and, on the other, ridges and peaks are the result of subsequent sculpturing by rain and rivers. It is of *ranges*, therefore, that we shall mainly speak.

The *surface* of the earth has now become cool and its mean temperature fixed, and is, therefore, *no longer contracting ;* but the *interior* is certainly still extremely hot, and still cooling and contracting. The effect of such interior contraction is to thrust the exterior crust upon itself horizontally with irresistible force, crushing it together with many complex foldings of strata, and causing it to bulge up in long wrinkles. *Such lines of bulging* *or wrinkles are mountain-ranges.* So much it was necessary to say to render what follows intelligible; but the origin of mountains is best taken up in connection with their *structure.*

Structure and Origin of Mountains.

Mountain-ranges are always made up of series of strata of immense thickness thrown into folds, as if they had been crushed together horizontally, and swelled up vertically. To illustrate: Suppose we had a number of layers of wax, or clay, or other plastic substance of different colors laid one atop another, as in Fig. 143, *A;* suppose, further, that the middle portions were softened a very little by gentle heat below, and the whole was then crushed together horizontally, as represented by the arrows. The middle softer portions would yield and be mashed together, thrown into folds and swelled up, as shown in Fig. 143, *B.* Now, this is exactly the way in

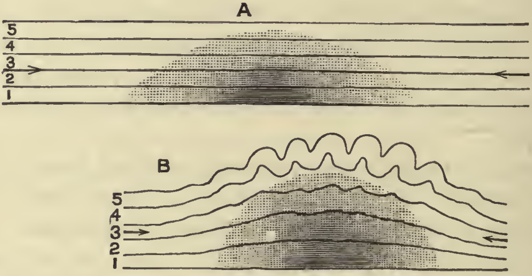

FIG. 143.

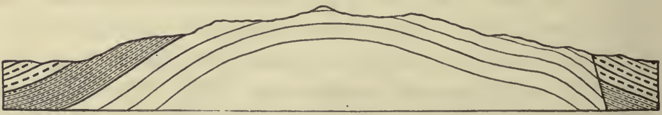

FIG. 144.—Section across the Uintah.

which mountain-ranges seem to have been formed. Sometimes, though rarely, there is but *one* great fold (Fig. 144); sometimes there are several open folds (Fig. 145); more commonly, especially in great mountains, there are many closely appressed folds (Figs. 146 and 147). In the Coast Range (Fig. 146) there are at least five alternate anticlines and synclines; in the Alps there are, in some places, seven alternate anticlines and synclines. It is evident that in these cases a great breadth of sediments is squeezed horizontally into a small space, and correspondingly swelled upward into a range. In the case of the Coast Range (Fig. 146), every two or two and a half miles of original breadth has been compressed into one mile. In the case of the Alps, probably every three miles of original breadth has been crushed into one mile, and, of course, correspondingly swelled up. Sometimes the mashing together is even far greater than represented in

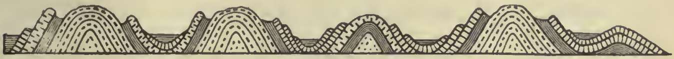

Fig. 145.—Section across the Jura.

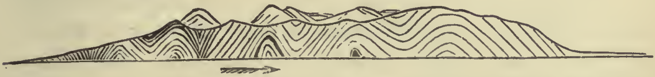

Fig. 146.—Section of Coast Range, showing plication by horizontal pressure.

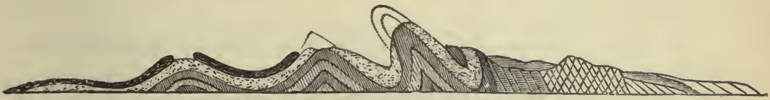

Fig. 147.—Appalachian chain.

these figures. Fig. 148 shows an example in the Alps, taken from Heim.

There is another evidence that mountains are formed wholly by horizontal crushing, viz., the phenomenon of *slaty cleavage.* We have already seen (page 195) that slaty cleavage always shows a crushing together horizontally, and an extension vertically, of the whole mass. Now, cleavage is always associated with folded strata and with mountain-ranges.

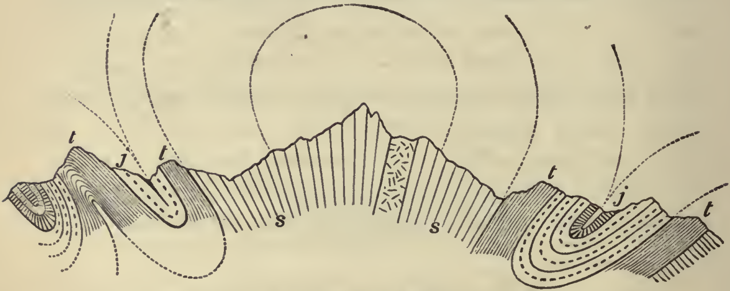

FIG. 148.—Section **across central Alps :** *j*, jurassic ; *t*, triassic ; *s*, schist.

Mountains are often spoken of as due to "*upheaval.*" There is no objection to the use of this term, if it be remembered that the upheaval is not usually due to a force acting *from below upward,* but to a horizontal force crushing together and swelling upward by thickening the whole squeezed mass.

We have, in Fig. 143, *B,* given the ideal structure of a mountain-range if there had been no erosion. But, of course, as soon as a mountain begins to rise, *rain-water begins to cut it away,* and in all mountains the amount cut away is immense, in many far greater than what is left. This fact is represented in the preceding figures (144–148). In all these figures, however, except the last, the range is composed wholly of stratified rock ; but in most great mountain-ranges we have an axis of *crystalline* rock, granitic or metamorphic, flanked on either side with uptilted and folded strata, as in Figs. 149, 150. It

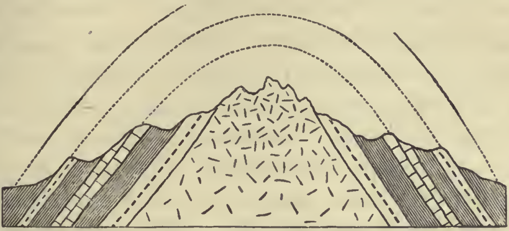

Fig. 149.—Ideal section, showing granite axis.

was formerly supposed that the igneous rock in fused condition has pushed up and broken through the strata and appeared above them. But it is far more probable that stratified rock once covered the whole, as shown by the dotted lines, and that subsequent erosion has exposed the

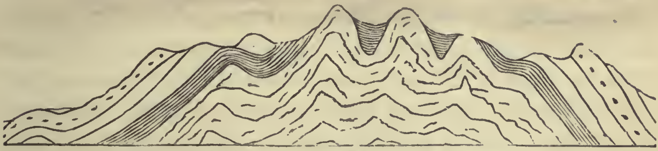

Fig. 150.—Ideal section of a mountain-range.

granitic or metamorphic rocks along the crest where the erosion was greatest. Furthermore, when we remember that mountains are composed of immensely thick series of strata, and that very thick strata are sure to be metamorphic in their lower parts (page 226), and, moreover, that granite is often but the last term of metamorphism of rocks, it becomes probable that even such mountains as those represented in Figs. 149, 150, are really composed wholly of horizontally mashed and crumpled strata, only that, on account of the great thickness and strong crumplings, these have become completely metamorphic in their lower parts.

Thickness of Mountain Sediments.—We have said that mountains are composed of enormously thick sediments, crushed together horizontally with many crumplings, and swelled up proportionally. We will now give examples of such thickness. The Appalachian consists of folded strata (Fig. 147) which, according to Hall, are not less than 40,000 feet, or nearly eight miles, in thickness. The Wahsatch consists of sediments which, according to King, are 50,000 feet, or nearly ten miles, in thickness. The Coast Range of California consists of folded cretaceous and tertiary. The cretaceous alone, according to Whitney, are 20,000 feet thick. The tertiary have not been measured, but cannot be less than 10,000 feet. So that at least 30,000 feet, or nearly six miles, thickness of sediments are involved in the folded structure of this range (Fig. 146). The strata of the Alps are not less than 40,000 to 50,000 feet thick. The same is true of all mountains.

Now, we must not imagine that this is evidence of the average thickness of strata, but only *revealed* in mountains by erosion, for the very same strata elsewhere are much thinner. For example, the same strata, which are 40,000 feet thick in the Appalachian Range, thin out westward until they are only 4,000 feet thick at the Mississippi River. The very same strata, which are 30,000 feet thick, in the Wahsatch, thin out eastward, and are only 1,000 feet thick on the Plains. Thus, then, *mountain-ranges, before they were upheaved, were lines of exceptionally thick sediments.* This may be regarded as certain.

Mountain-Ranges are Upheaved Marginal Sea-Bottoms.—Where, then, do we find exceptionally thick sediments? Where, but along marginal sea-bottoms? We have seen (page 48) that here are accumulated nearly the whole *débris* of continental erosion. Therefore, *mountain-ranges before they were upheaved, were marginal sea-bottoms on which have accumulated enormously* *thick sediments.* Every one of our great mountain-ranges can be shown by geological evidence, which we cannot give here, to have occupied this position until the time of their birth.*

Different Stages of Mountain-Life.—We have said "*until birth,*" but it must not be supposed that there was anything sudden about it. The emergence above water we call *its birth,* but a mountain continues to grow steadily through *many ages.* Meanwhile, as soon as it is born, erosion commences, and continues with increasing rate as the range grows higher. When the mountain stops growing, erosion begins to destroy it, and finally levels it completely. Thus, in every mountain there is a period of birth, a period of growth, a period of maturity, a period of decay, and a time of death or *obliteration.* Many of the earliest mountains have been entirely swept away. We know their places only by their *folded structure*—fossil bones of extinct mountains.

Why Yielding occurs along Lines of Thick Sediments.—Perhaps the pupil has already asked himself, "Why does yielding occur only along lines of thick sediments?" The probable reason is, that great accumulations cause the rise of the interior heat of the earth toward the surface, as already explained on page 227. This heat, in the presence of the water included in the sediments, causes these, as also the earth-crust beneath, to soften or even semi-fuse; and thus creates a *line of weakness,* and therefore of yielding. This is represented in the experiment with the wax, on page 240, by the gentle softening of the middle part.

Cause of the Lateral Pressure.—If it be further asked, "What is the cause of the lateral pressure?" we can only say that this is an obscure point, and one much discussed. It is probable, however, that it is due, as already stated (page 239), to the interior contraction of the earth, by which the crust, following down the shrinking nucleus, is thrust upon itself laterally with irresistible force. Mountain-ranges are the lines of yielding.

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* For evidence, see "Elements of Geology," p. 265.

Other Associated Phenomena.—If we clearly apprehend the foregoing account of the structure and origin of mountains, other associated phenomena are easily understood: 1. The strong bendings of the strata necessarily produce *fissures,* mainly parallel to the bendings—i.e., to the axis of the range, and to one another. 2. Since these fissures break through many miles of strata, it is natural that igneous matter should come up through them to the surface, and therefore that volcanic and especially great *fissure eruptions* should be associated with mountain-ranges, and that where the overflows are cut away by erosion we should find *dikes.* Again, 3. As the mashing goes on steadily, the fissures first formed would be certain to slip, and thus we find great faults often associated with mountains. Again, 4. The *formation* of a fissure or the subsequent slipping of a fissure could not fail to produce an earth-jar; and thus *earthquakes* are commonest in mountain-regions. Finally, 5. Fissures which did not fill at the moment of formation by igneous injection would certainly fill slowly afterward by percolating water depositing minerals, and thus, also, *mineral veins* are commonest in mountain-regions.

Thus we see now the truth of the proposition with which we set out, viz., that mountains are the culminating points—the theaters of greatest activity—of all geological agencies; of aqueous sedimentary agencies in preparation for the mountain; of igneous agencies in the birth and growth, and of aqueous erosive agencies in sculpturing and final destruction of the mountain.

Mountain-Sculpture.

In the life-history of a mountain-range, the work of water in *sculpturing* is no less important than the work of interior heat in *formation.* If the mountain is rough-hewed by the latter, it is shaped and chiseled by the former. The great swell of the crust, which is only seen *from a distance,* is due to igneous agency; but all the scenery, which so charms us when we are *among* mountains, is due wholly to erosion. Moreover, there is a peculiar charm in the study of the latter, because it is more easily understood. The cause of mountain-origin is obscure, and the folded structure of mountains is hidden, and can only be unraveled by the skillful geologist; but the forms of mountain-sculpture may be studied by all, and their study gives great additional charm to mountain-travel.

Resulting Forms.—The forms produced by erosion are infinitely various, depending upon the kind of rock and upon the amount and style of folding. They are, therefore, of great interest also as revealing interior structure. We can only touch very lightly on a few of the most common and characteristic forms.

1. **Horizontal Strata.**—These, when sufficiently *hard,* give rise to *table* forms, the top of the table being determined by a hard stratum of some kind, as *sandstone,* or by a *lava-flow.* In the latter case, however, we have this form, whatever be the position of the underlying strata (see Fig. 6, page 24). Good examples of this form are seen in Illinois and in Tennessee (Fig. 151), and especially in the *mesas* of the Plateau region (Fig. 7, page 25).

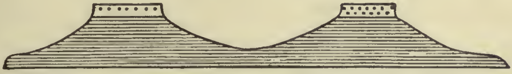

FIG. 151.—Table-mountains.

If, on the contrary, the horizonal strata are *soft,* and yield easily to erosion, they are worn into the most fantastic forms—conical, castellated, pinnacled—such as are found in the "Bad Lands" of the West, which are produced by erosion of the dried-up lake-deposits of this region (Fig. 152).

2. **Gently Undulating Strata.**—These, also, by erosion give rise to table-topped mountains; but, if carefully examined, the ridges are seen to be *synclinal*, and the valleys *anticlinal*. Fine examples of this form are found on the western slopes of the Appalachian chain, where the folds of the strata are dying away in gentle undulations (Fig. 149). The reason of this form is that the hollows become hardened by *compression*, while the original saddles are loosened or even broken by *tension*, and erosion therefore takes effect mainly on these latter.

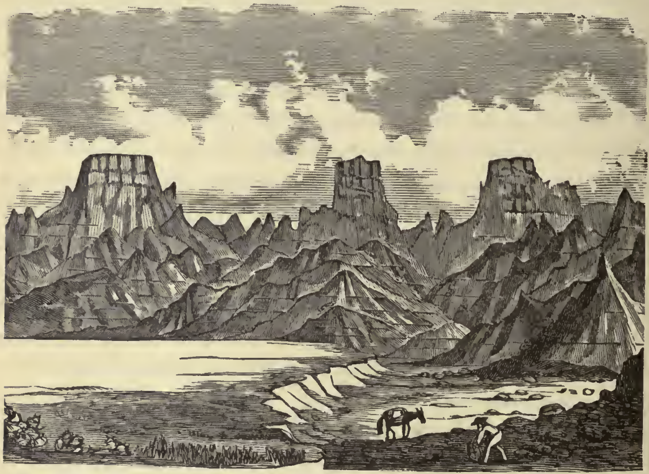

FIG. 152.—Mauvaises Terres, Bad Lands. (After Hayden.)

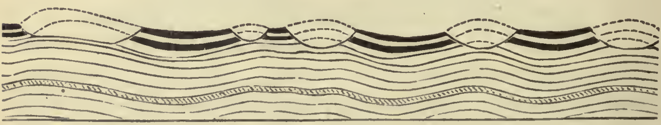

FIG. 153.—Section of coal-field of Pennsylvania. (After Lesley.)

3. **Highly Inclined Outcropping Strata.**—These give rise to sharp ridges, determined each by the outcrop of a hard stratum, with intervening valleys determined by the outcrop of softer strata (Fig. 154). This structure is finely displayed on the flanks of Western mountains and the mountains of Tennessee, and especially in the mountains of Virginia. Standing on the top of Warm Springs Ridge, twelve or more mountain-waves may be counted, each crest determined by the outcrop of a hard sandstone.

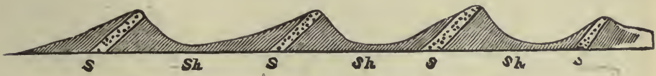

FIG. 154.—Parallel ridges.

4. **Very Gently Inclined Outcropping Strata.**—These, in the Plateau region, give rise to a remarkable series of nearly level tables, terminated by cliffs, a hard stratum forming the surface of the table. In Fig. 156, taken from Powell, the successive tables are fifteen to twenty miles wide, and the cliffs 1,500 to 2,000 feet high. The manner in which these are formed is illustrated in the diagram, Fig. 155, in which *a, b, c, d* are hard strata. The dotted space shows the general erosion.

5. **Highly Metamorphic and Granitic Rocks.**—These reveal internal structure much less perfectly than unchanged stratified rocks. Usually the inequalities are very irregular, the peaks being determined by harder, and the valleys by softer, spots. In some cases, however, the peculiar forms may be easily explained. Thus, in the

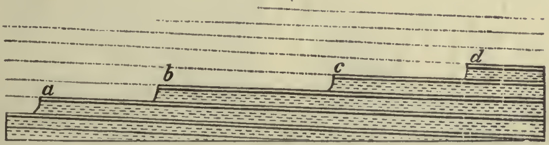

FIG. 155.—Dotted lines show material carried away by erosion.

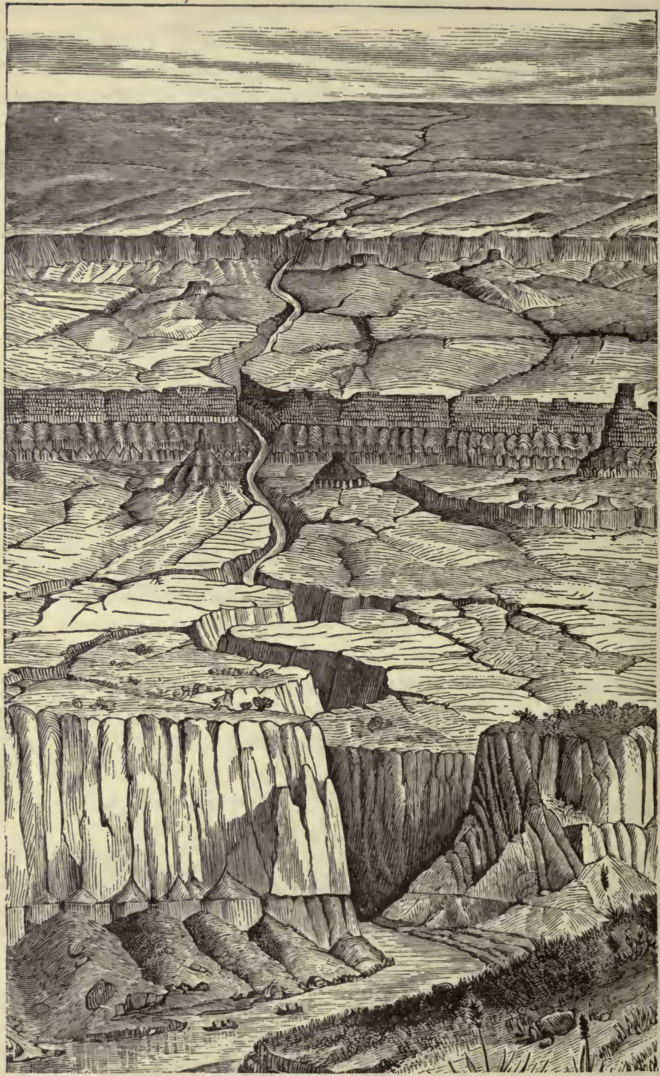

FIG. 156.—Bird's-eye view of the Terrace Cañon. (After Powell.)

high Sierra region, a remarkable dome-structure is very characteristic of the scenery. This is determined by a huge concentric structure of the granite, as in Fig. 157.

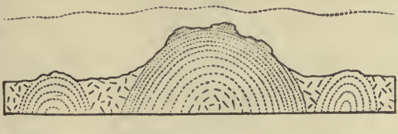

FIG. 157.—Ideal section showing dome-structure. Dotted line above shows original surface.

This, however, must not be confounded with *arched strata.* These great domes are still scaling off concentrically.

6. **Outbursts of Igneous Rocks through Dikes** often give rise to prominent ridges on account of their superior hardness. Examples are found in the trap ridges of the Connecticut Valley and in many other places.

7. **The Nature of the Erosive Agent.**—The scenic forms of mountains are also largely determined by the nature of the erosive agent. Simple *water* tends, by erosion, to form rounded summits and ridges, and narrow V-shaped gorges. *Ice,* on the contrary, tends to make pinnacled summits (*aiguilles*) and comb-like ridges, and broad, meadow-like valleys.

CHAPTER VI.

DENUDATION, OR GENERAL EROSION.

Definition.—Denudation is a term used to designate the aggregate results of all erosive agents. Its correlative is sedimentation. In the preceding pages we have given the effects of erosion in many *individual* cases; but some general idea of the amount which has taken place, under the action of all agents throughout all geological times, and some very general estimate of geological time based thereon, seem important, as a fitting preparation for Part III, or Historical Geology, which deals especially with *time*.

Agents of Erosion.—The possible agents of erosion are—1. Rain and rivers. 2. Snow and ice. 3. Waves and tides. 4. Oceanic currents. Of erosion by the last, we have no observation. Oceanic currents run on a bed and between banks of still water, and therefore produce no erosion (page 48). We may probably leave them out of account. Waves and tides are very powerful erosive agents, but their action is confined wholly to the shore-line. It has been estimated that, though so conspicuous, their aggregate effect is certainly less than one fifth that of rain and rivers. Snow is but a different form of rain, and glaciers a different form of rivers; therefore, in so rough an estimate as we are about to make, we may safely base our estimate upon the action of rain and rivers. Our object, then, will be to give some very general idea of the *amount* of denudation which has taken place in geological time; then of the *rate* of rain and river erosion; and then a rough estimate of the *time* necessary to do the work.

Modes of determining Amount of Denudation.—There are many ways in which geologists determine the amount of denudation. In case of faults, as in Fig. 158,

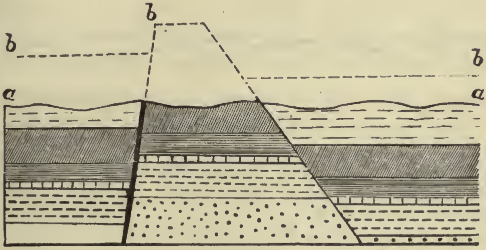

FIG. 158.

in which the strong line, *a a*, represents actual surface, there must have been great erosion to obliterate all surface indications of the slip. Now, there are cases of slips 20,000 feet vertical, as in Pennsylvania and on the north side of Uintah, in which surface indications are entirely removed by erosion. Again, in case of isolated erosion-peaks, like Fig. 159, it is evident that the whole intervening country has been carried away. Now, such peaks are often 2,000 to 3,000 feet high. But the most universal means of estimating the amount of erosion is by restoration of folded strata. This is shown in Fig. 160, and in many of the preceding figures on mountains.

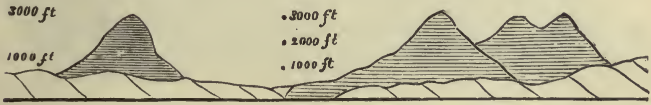

FIG. 159.—Denudation of red sandstone, northwest coast of Ross-shire, Scotland.

By all these methods it has been estimated by British geologists that at least 11,000 feet of thickness has been removed from the whole mountainous and hilly portions of the British Isles, and by American geologists that 20,000 feet have been removed from the Appalachian region. This has all taken place since the Palæozoic, which is certainly not more than one quarter of the recorded history of the earth. But the finest examples are from the Plateau region. Fig. 161 represents a portion of the Uintah Mountains, the lower portion as it really is, the upper as it would be if restored with its great fault. According to Powell, 25,000 feet have been removed from the whole area represented, and this, too, since the beginning of the Tertiary, which is but a small fraction of geological time. According to Powell and Dutton, over the whole

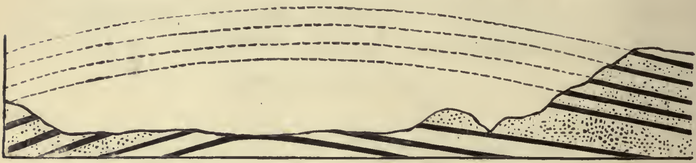

Fig. 160.—Section across middle Tennessee. The dotted lines show the amount of matter removed.

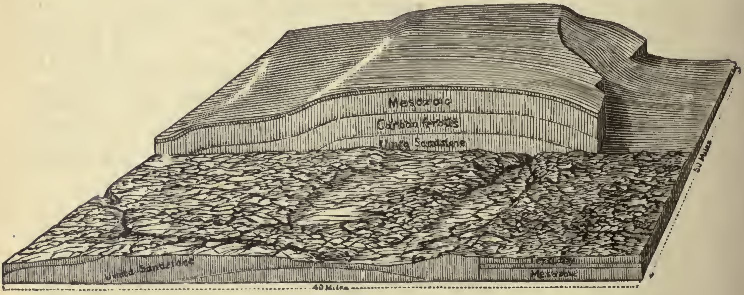

Fig. 161.—Uintah Mountains—upper part restored, showing fault; lower part showing the present condition as produced by erosion. (After Powell.)

Plateau region, an area of not less than 200,000 square miles, an average of 6,000 to 8,000 feet and an extreme of 12,000 feet, has been removed by erosion, and all since the Middle Tertiary. From these examples it is impossible to resist the conclusion that the average erosion over all land-surfaces has been at the very least several thousand feet.

There is another way of making the estimate of the amount of general erosion. Evidently the correlative and measure of erosion is *sedimentation.* The *débris* of erosion have been accumulated as stratified rock. Now, the average thickness of strata can not be less than several thousand feet. Taking it only as 2,000 feet (it is certainly very much more), since the area of ocean is, and probably always was, three times the area of the land, this would require at least 6,000 feet erosion of all land-surfaces. We may therefore say, with the utmost confidence, that over all land-surfaces more than 6,000 feet thickness has been removed by erosion.

Time.—Now, we have seen (page 19) that the *rate* of rain and river erosion is about one foot in 5,000 years. At this rate it would take 30,000,000 years to do the work which we actually find has been done. The time was probably much greater. Exceptions may be taken to *some points* of our calculation, but, we are sure, not to the *result.* But this, be it more or less, represents only *recorded* history. Beyond this, again, is the infinite abyss of the *unrecorded.*

PART III.

HISTORICAL GEOLOGY.

CHAPTER I.

GENERAL PRINCIPLES.

Geology is essentially a history. But there are two points of view from which history may be studied, viz.: 1. As a *chronicle* of thrilling events. 2. As the *science* of the *laws of succession,* and of the *causes* of these events. The interest in the one case is *dramatic,* in the other, *scientific.* The one addresses itself mainly to the imagination, the other to the reason. It is almost unnecessary to say that geology is a history in which the second element predominates. It is a history of the *evolution* of the earth and of its inhabitants. Now, there are certain general laws of evolution in all departments of nature—certain general principles underlying *all* history. The most important of these we wish to fix in the mind of the pupil by comparing geology with human history:

1. Human history is divided and subdivided into eras, ages, periods, epochs, etc., determined by great events. These divisions of time are recorded in separate volumes, chapters, sections, etc., according to their importance. So, also, the history of the earth is divided into *eras, ages, periods,* etc., determined by great changes in physical geography, climate, and forms of organisms; and these

divisions of time are recorded in separate rock *systems,* rock *series,* rock *formations,* according to their importance.

2. These divisions of time, in human history, usually graduate, more or less insensibly, into each other. Yet, at certain points, called *revolutions,* the steps of change are more rapid. So, also, in geological history, the eras, ages, periods, etc., usually graduate into each other. And yet there are certainly here, also, times of revolution, in which the steps of change are far more rapid. Thus all history, human or geological, consists of periods of comparative quiet and prosperity, during which the forces of change are gathering strength ; and periods of revolution, when these forces show themselves in conspicuous effects.

3. In human history, what is distinctively called an *age,* is marked by the dominance of some characteristic social force or principle. Thus, we have had an age of *chivalry,* and we look forward to an age of *reason.* So, also, in geology, what is distinctively called an *age,* is marked by the dominance of some particular *class* of animals or plants. Thus, we have an age of *mollusks,* an age of *fishes,* an age of *reptiles,* etc., in which these several classes are successively the dominant types. Now, since the divisions graduate into each other, it is to be expected that the characteristic of each age will commence in the preceding age. This we shall call the *law of anticipation.*

4. In human history each dominant characteristic, of course, arises, culminates, and *declines ;* but it does not, therefore, *perish.* It only becomes subordinated to the next coming and higher characteristic, and society thus becomes not only higher and higher, but also more and more complex in its structure. So, also, in geology we shall find that as each dominant class culminates and declines, it does not perish, but only becomes subordinated to the incoming and higher dominant class, and thus the whole organic kingdom becomes not only higher and higher, but also more and more complex in its struc-

ture as a whole. This is represented in the diagram (Fig. 162), in which *A B* is the course of time, and the rising and declining curved lines the successive culminations of five great dominant classes of animals.

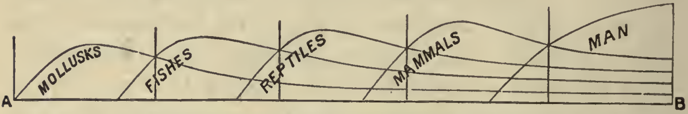

FIG. 162.—Diagram illustrating the rising, culmination, and decline of successive dominant classes, and the increasing complexity of the whole.

5. As in human history, while the whole race, or at least Christendom, advances together, and yet there are special differences in *rate* or *direction* of advance peculiar to each country and constituting its national civilization; so also in geology, while the whole earth and its inhabitants in every part are affected with a common onward movement in evolution, yet there are special differences in *rate* or *direction* of evolution, characteristic of each great division of the earth. The most marked example of this is Australia, which is far behind other continents in the march of evolution.

6. In a *written* human history, there are two ways in which we may judge of the subdivisions, viz.: 1. By the artificial divisions of the record, i. e., volumes, chapters, etc.; or, 2. By the nature of the most important contents. In a well-written history these will correspond with each other. So also in geology there are two modes of separating and determining the limits of the great divisions and subdivisions of earth-history, viz.: 1. By unconformity of the rock record; or, 2. By the change in the organic contents. These usually correspond, because they are produced by the same cause. But, if there be a discordance (as there may be locally), then we follow the changes in the organic forms, rather than the unconformity of the rocks.

Divisions of Geological History. Eras.—It is on these principles that the whole history of the earth, and the rocks in which it is recorded, has been divided and subdivided. The primary divisions, or *eras*, are five in number, each embodied in a corresponding system of rocks: 1. Archæozoic,* in the Archæan or Primary or Laurentian system of rocks; 2. Paleozoic,† in the Palæo-

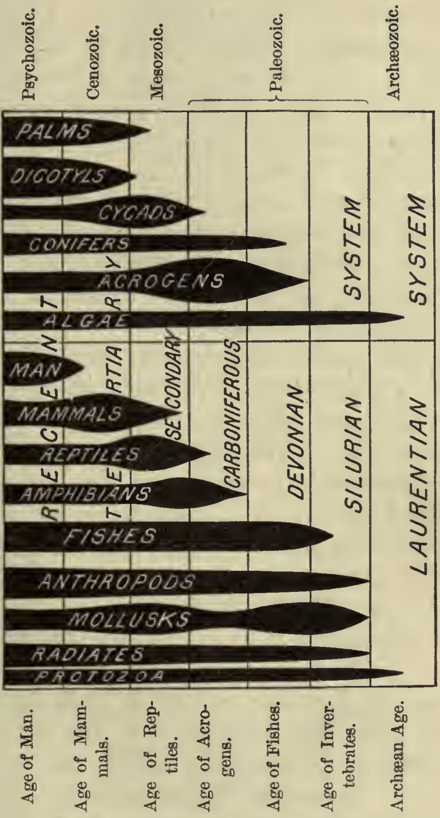

FIG. 163.

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* Archæozoic = primeval animal life. † Paleozoic = old life.

zoic, or sometimes called transition system of rocks; 3. Mesozoic,* in the Secondary system; 4. Cenozoic,† in the Tertiary and Quaternary systems; and, 5. Psychozoic,‡ in the present system of sediments. These five are separated in the diagram (Fig. 163) by the heavy lines, and their names are given on the right.

How separated.—These primary divisions (unless we except the last) are separated by a universal or almost universal unconformity, indicating wide-spread changes in physical geography at these times; and by sweeping changes in organic forms, involving not only species, but genera, families, and orders. The changes between the last two were not so great either in the rocks or in the organisms, but the introduction of man, and the sweeping changes going on now by his agency, are deemed of sufficient importance to make this a primary division.

Ages.—The whole history of the earth is divided, on a different principle, into seven *ages*, characterized each by a dominant class. In some cases these correspond to, and in some are subdivisions of, the eras. These ages, and their corresponding rocks, when they are subdivisions, are separated usually by unconformity, but not so universal; and by changes of organisms, but not so sweeping. They are—1. Archæan or Eozoic age, corresponding to the Eozoic era. 2. Age of Mollusks, or age of Invertebrates, corresponding to the Silurian system of rocks. 3. The age of Fishes, corresponding to the Devonian. 4. The age of Acrogens, or age of Amphibians, corresponding to carboniferous strata. 5. The age of Reptiles, corresponding to the Mesozoic era and Secondary rocks. 6. The age of Mammals, corresponding to the Cenozoic era and the Tertiary and Quaternary rocks. 7. The age of Man, corresponding to the Psychozoic era and the present sediments.

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* Mesozoic = middle life. † Cenozoic = recent life. ‡ Psychozoic = rational life.

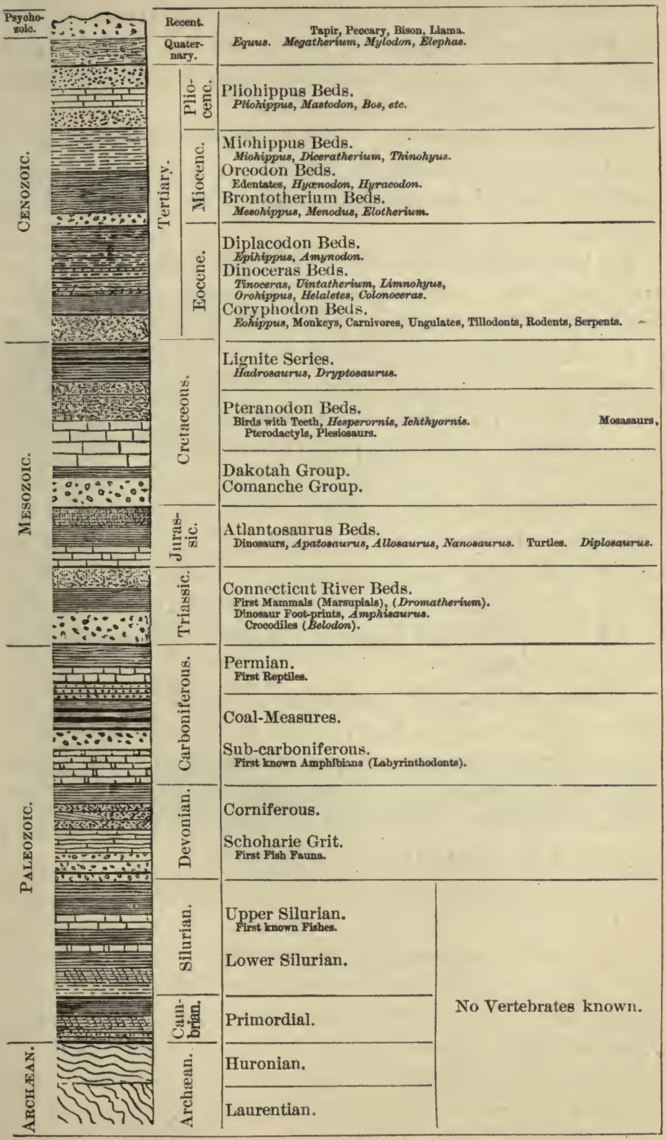
Psychozoic.
Recent.
Quaternary.
Tapir, Peccary, Bison, Llama.
Equus. *Megatherium, Mylodon, Elephas.*
Cenozoic.
Tertiary.
Pliocenc.
Pliohippus Beds.
Pliohippus, Mastodon, Bos, etc.
Miocenc.
Miohippus Beds.
Miohippus, Diceratherium, Thinohyus.
Oreodon Beds.
Edentates, *Hyænodon, Hyracodon.*
Brontotherium Beds.
Mesohippus, Menodus, Elotherium.
Eocene.
Diplacodon Beds.
Epihippus, Amynodon.
Dinoceras Beds.
Tinoceras, Uintatherium, Limnohyus, Orohippus, Helaletes, Colonoceras.
Coryphodon Beds.
Eohippus, Monkeys, Carnivores, Ungulates, Tillodonts, Rodents, Serpents.
Mesozoic.
Cretaceous.
Lignite Series.
Hadrosaurus, Dryptosaurus.
Pteranodon Beds.
Birds with Teeth, *Hesperornis, Ichthyornis.*
Pterodactyls, Plesiosaurs.
Mosasaurs,
Dakotah Group.
Comanche Group.
Jurassic.
Atlantosaurus Beds.
Dinosaurs, *Apatosaurus, Allosaurus, Nanosaurus.* Turtles. *Diplosaurus.*
Triassic.
Connecticut River Beds.
First Mammals (Marsupials), (*Dromatherium*).
Dinosaur Foot-prints, *Amphisaurus.*
Crocodiles (*Belodon*).
Paleozoic.
Carboniferous.
Permian.
First Reptiles.
Coal-Measures.
Sub-carboniferous.
First known Amphibians (Labyrinthodonts).
Devonian.
Corniferous.
Schoharie Grit.
First Fish Fauna.
Silurian.
Upper Silurian.
First known Fishes.
Lower Silurian.
Cambrian.
Primordial.
Archæan.
Huronian.
Laurentian.
No Vertebrates known.

FIG. 164.—Section of the earth's crust, to illustrate vertebrate life in America. (Slightly modified from Marsh.)

In the diagram (Fig. 163) the different rock-systems are placed one on top of the other, and the vertical black spaces represent by their breadth the relative dominance of different classes at different times.

Periods and Epochs.—The subdivisions of these again into periods and epochs are founded on more local unconformities, and especially on less important changes in the species.

We have already, on page 204, given a schedule of the most important divisions and subdivisions adopted in this work; but we shall not treat separately all of these. As in human history, so in geology, the earliest times are little known, and are touched lightly. As we come toward the present, and events thicken, we shall take up subdivisions more and more—first ages, then periods, and, finally, even epochs. We give here also (Fig. 164) a generalized section of American strata, which will be found useful for reference. It must not be supposed, however, that all these strata occur in any one place. It is an *ideal* section, in which all the most important American strata occurring in different places are brought together and arranged in the order of *time.*

We are now ready to commence a rapid survey of the history of the earth. But it must be understood that we can commence only where the record commences. Before this is the abyss of the unrecorded, of which we know nothing positive. Before the historic is the prehistoric; no history can recall its own beginning.

CHAPTER II.

ARCHÆAN SYSTEM AND ARCHÆOZOIC ERA.

The events recorded in this oldest system of rocks, in this first volume of the *book of time*, are so few and so imperfectly recorded that their chief interest consists in the fact that they are the first. There is a fascination about the beginning—the mythical period—of all history. The distinctness of this system was for a long time unrecognized. It has now, chiefly by the labors of American geologists, been completely established. In no single instance have these rocks been found to graduate into the Paleozoic. There is absolutely everywhere an unconformity between them and every other system. No such complete and universal break occurs anywhere else in the rocky series as occurs here (Fig. 165). It is, therefore, properly called a distinct system and a distinct era—more distinct, in fact, than any other.

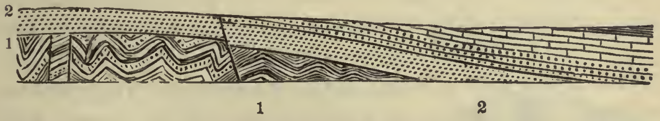

Fig. 165.—Section showing Primordial unconformable on the Archæan : 1, Archæan or Laurentian ; 2, Primordial or lowest Silurian. (After Logan.)

Here, then, we have the *oldest known* rocks. Are they, then, absolutely the oldest—the *primitive* rocks, as some imagine ? By no means. They are *stratified* rocks, and therefore consolidated sediments, and therefore, also, the *débris* of still older rocks, of which we know nothing. Thus, we seek in vain for the absolutely oldest, the primitive crust. As already said, no history can write its own beginning.

Character of these Rocks.—We can only say, in brief, that they do not differ very conspicuously from metamorphic rocks of other times. They were probably originally sands, clays, and limestones, much like those of other times; but, in this case, *always very highly metamorphic and strongly crumpled* (Fig. 166). The sands are thereby changed into quartzites, the clays into schists, gneisses, and even granites, and the limestones into marbles. Along with these, however, are associated two kinds of beds, which are worthy of note, viz., beds of *iron-ore* and beds of *graphite.* In Canada the whole series is not less than 40,000 feet thick.

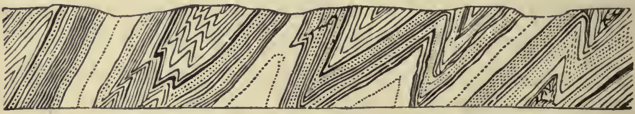
FIG. 166.—Contortion of Laurentian strata. (After Logan.)

The greatest beds of iron-ore known in any strata are found here. The great iron-ore beds of Sweden, of Lake Superior (Fig. 167), of New Jersey, and the Iron Mountain of Missouri, are in these rocks. Recently, in southern Utah, in rock of this age (or possibly later), have been found the greatest iron-deposits, perhaps, in the world. The strata here stand on edge, and the beds of iron-ore, being very hard, have been left by erosion standing out as black, castellated, inaccessible crags, 300 feet high, 1,000 feet long, and 500 feet thick. In Canada and elsewhere graphite also occurs in immense beds, sometimes pure, sometimes mixed with the rock.

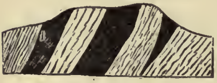
FIG. 167.

Area.—1. These rocks cover the whole of Labrador, nearly the whole of Canada (passing into New York in the region of the Adirondacks), then extend northwest probably to the Arctic regions. This, the greatest Archæan area in North America, forms a broad, open **V**, inclosing in its arms Hudson Bay. 2. The next largest area is a broad space extending from New England to Georgia, including the Blue Ridge and the eastern slope of the Appalachian. 3. The axes of many of the great mountain-ranges, such as the Colorado, Park, and Wahsatch Ranges, and possibly the Sierra Nevada. 4. Some small, isolated spots, one in Texas and one in Missouri. In the map (page 272) these are represented by $\overset{\mathrm{vv}}{\mathrm{v}}$.

Physical Geography.—These being *stratified* rocks, it is evident that the whole Archæan area was sea-bottom at that time. Where, then, was the land from which this *débris* was derived? Of this we know nothing. Some have thought that it was to the northeastward. We shall see hereafter that the continent developed southward and westward.

Amount of Time.—The Archæan rocks are of enormous thickness, probably equal to all other subsequent rocks put together. The amount of time represented is, therefore, probably equal to all the rest of recorded history of the earth. And yet how meager the record! It is the same with the earliest human history.

Life.—Did any living thing exist at that time? This is a very important question, but we can not yet answer it with absolute certainty. There are, however, some good evidences of life: 1. Iron-ore is accumulated *now,* and therefore probably also in earlier times, only by means of decaying organic matter (page 89), and is, therefore, justly regarded as a *sign* of life and a *measure* of its quantity. 2. Graphite is regarded as the highest anthracitic condition of *coal;* and coal is a positive sign of organic matter, and therefore of the previous existence of life. Limestone, as we have seen (pages 114–117), is *now,* and at previous geological times, usually, though not always, of organic origin.

Judging from these signs, it would seem that life was not only present, but in large quantity. Can we say anything as to its kind? Are there any fossils? Here we must answer still more doubtfully. Some curious forms are found which are supposed to be those of the lowest order of animals (*compound Protozoa*). These have been called eozoön or *dawn-animal,* and therefore some have called this first era eozoic. Most, however, do not accept this animal, and prefer the name *Azoic* (no animal life), or, better still, Archæan or Archæozoic, as carrying no implication.

In conclusion, we may say that the existence of the lowest forms of vegetable life is *almost certain,* and of the lowest forms of animal life *probable.*

CHAPTER III.

PALEOZOIC ROCKS AND ERA.

Section I.—General Description.

The Lost Interval.—Between the Archæan and Paleozoic rocks occurs the greatest and most universal break in the whole stratified series. At this point in time occurred the greatest and most wide-spread changes in physical geography and climate which has ever occurred in the history of the earth. The justification for this statement is found in the fact that everywhere, even in the most distant localities, we find the lowermost Paleozoic (Primordial) lying unconformably on the Archæan. No one has yet seen the two series continuous. Now, when we remember that unconformity always means a previous eroded land-surface (page 192), and stratified rock a sea-bottom, we easily perceive how wide-spread the changes of physical geography must have been at this time. Again, when we remember that unconformity also always means a *lost interval* unrecorded at the place observed, and that the unconformity exists at all observed places, we at once see that right here is an unrecovered, probably an irrecoverable, *lost interval of time.* During the lost interval wide areas of land existed, which were afterward submerged and covered with Paleozoic sediments. As compared with the early Paleozoic, it was evidently a *continental* period.

Corresponding with the great physical changes here, there was also immense advance in life-forms. During the Archæozoic, as we have already seen, the life, if any, was only of the lowest possible kind. Life-forms had not differentiated into distinct, recognizable species. There was not yet what could justly be called a fauna and flora. Then came the lost interval, represented by the unconformity. Of what took place then we know nothing. When the record opens again with the Paleozoic, we have already an abundant and diversified fauna and flora. Even in the lowest Primordial we find all the great departments of *Invertebrates,* and nearly all the classes of these departments, already represented. It certainly *looks like* a sudden appearance of somewhat highly organized animals, without progenitors. But we must not forget the *lost interval.* It is probable that during this period of rapid physical changes there were also rapid changes in organic forms.

It is for these reasons that the Paleozoic is regarded as opening a new *era,* and, in fact, the most distinct in the history of the earth. We have explained its distinctness from the Archæan below, but we shall find hereafter that it is almost equally distinct from the Mesozoic above. It is separated on both sides by unconformity and by changes in life—a distinct volume with, as it were, blank boards on either side.

Rock-System.—There is nothing very noteworthy in the character of the rocks of the Paleozoic. Only this may be said : as compared with the Archæan rocks, they are far less universally thick, metamorphic, and crumpled. In *mountain-regions,* indeed, they are very thick (40,000 feet in the Appalachian), very metamorphic, and very much folded ; but in level regions they are often much thinner, entirely unchanged, and level-lying. For example, in passing from the Appalachian westward, we find the following four kinds of change : 1. In the Appalachian the Paleozoics are 40,000 feet thick ; they thin out westward, until at the Mississippi River they are only 4,000 feet. 2. In the former, sands, grits, and clays predominate; in the latter, limestones. 3. In the former the rocks are strongly folded; these folds die out through gentle undulations to level-lying strata in the latter. 4. In the former the rocks are highly metamorphic; in the latter they are wholly unchanged.

Area in the United States.—1. *Eastern Paleozoic Basin.* The Paleozoic rocks cover a large continuous area in the very best part of the United States. This area is bounded on the north by the chain of the Great Lakes; on the east by the Blue Ridge of the Appalachian chain; on the south by a line running through mid-Alabama, turning northward to the mouth of the Ohio River; then south through mid-Arkansas and Indian Territory; on the west by the Western grassy plains. 2. Besides this great area, there are several considerable areas scattered about in the Plateau region and exposures along flanks of mountains of the Plateau and Basin regions.

Physical Geography.—The physical geography of the eastern portions of the North American Continent in Paleozoic times can be made out with considerable certainty. In fact, we can in many places trace the *Primordial shore-line.* Immediately in contact with the Canadian Archæan on the north, and the Blue Ridge Archæan on the east, are found patches, or continuous lines of a coarse sandstone, which contain all the marks characteristic of shore-lines, such as worm-tubes, worm-trails, crustacean tracks, ripple-marks, rain-prints, etc. This is the old *Primordial beach.* At the beginning of Paleozoic times, therefore, the whole Paleozoic basin was covered by a sea which beat against a land-mass to the north (Canadian Archæan area), and a land-mass to the east (Blue Ridge Archæan area). This is called the *great interior Paleozoic Sea.* There was also a large land-mass in the Basin region, and smaller masses, probably islands, in the Colorado mountain-region, but the exact limits of these are not known. The map (Fig. 168) represents the present state of our knowledge on this subject. It is probable, however, that the Eastern land-mass (Blue Ridge Archæan area) was larger than represented, having been subsequently covered by later deposits, and partly, even now, by the Atlantic Ocean.

The change in the rocks, in passing westward from the Appalachian region, is completely explained by the position of the Appalachian region and the subsequent formation of the mountains. This region was then the marginal bottom of the interior sea, receiving abundant and coarse sediments, which became finer and thinner seaward. This thick marginal line then yielded, was strongly folded and highly metamorphosed in the act of mountain-making which took place at the end of the Paleozoic.

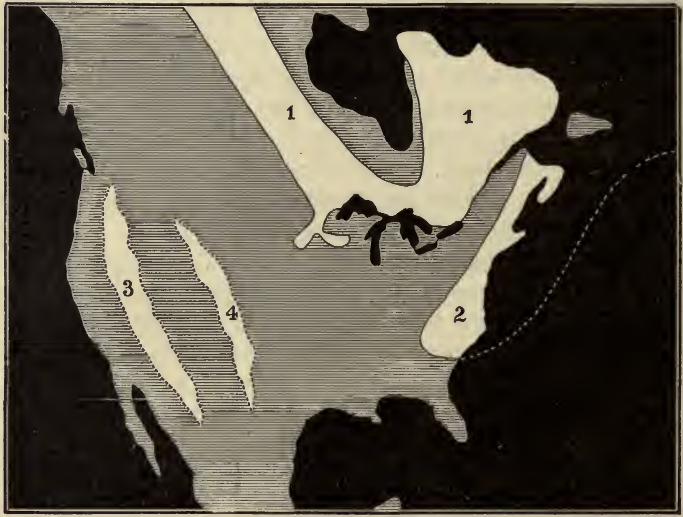

Fig. 168.—Map of physical geography of Primordial times: existing seas and lakes, black; continental seas of that time, light shade; land of that time, white. The white dotted line shows the probable shore-line of 2 at this time.

Growth of the Continent during Paleozoic Times.—The map (Fig. 168) represents the continent at the *beginning* of the Paleozoic. But during that era there was a steady *growth* from this nucleus by addition southward and westward, until, at the end, the whole of the Paleozoic areas were reclaimed from the sea, and the continent was nearly, though not exactly, that represented on page 349. It will be seen that the continent was already outlined at the beginning of the era, and was steadily developed toward its present form. We shall hereafter trace this development to its completion.

Subdivisions of the Paleozoic.—The Paleozoic era and strata are divided into three ages, each represented by corresponding rock-systems : 1. *The age of Mollusks*, or of *Invertebrates*, represented by the *Cambrian* and *Silurian* system ; 2. *The age of Fishes*, by the *Devonian ;* 3. *The age of Acrogen Plants* and *Amphibian Animals*, by the *Carboniferous*. These three rock-systems, in many parts of the world, are unconformable with each other ; but in the United States they are usually entirely conformable. Nevertheless, their life-systems (organic forms) are here, as everywhere, quite different.

All these subdivisions are well represented in the Paleozoic basin of the United States (Fig. 169). In the following map of the main divisions of the geological strata of the Eastern United States, the rocks representing these three ages are all shown. It is important to study this map well, for it will be referred to frequently hereafter in connection with more recent strata.

SECTION II.—LOWER PALEOZOIC OR CAMBRIAN AND SILURIAN SYSTEM. AGE OF INVERTEBRATES.

Rocks ; Name.—These rocks are called Cambrian and Silurian, from the Roman name for Wales and the Welsh, because they were first studied in Wales, by Sedgwick and

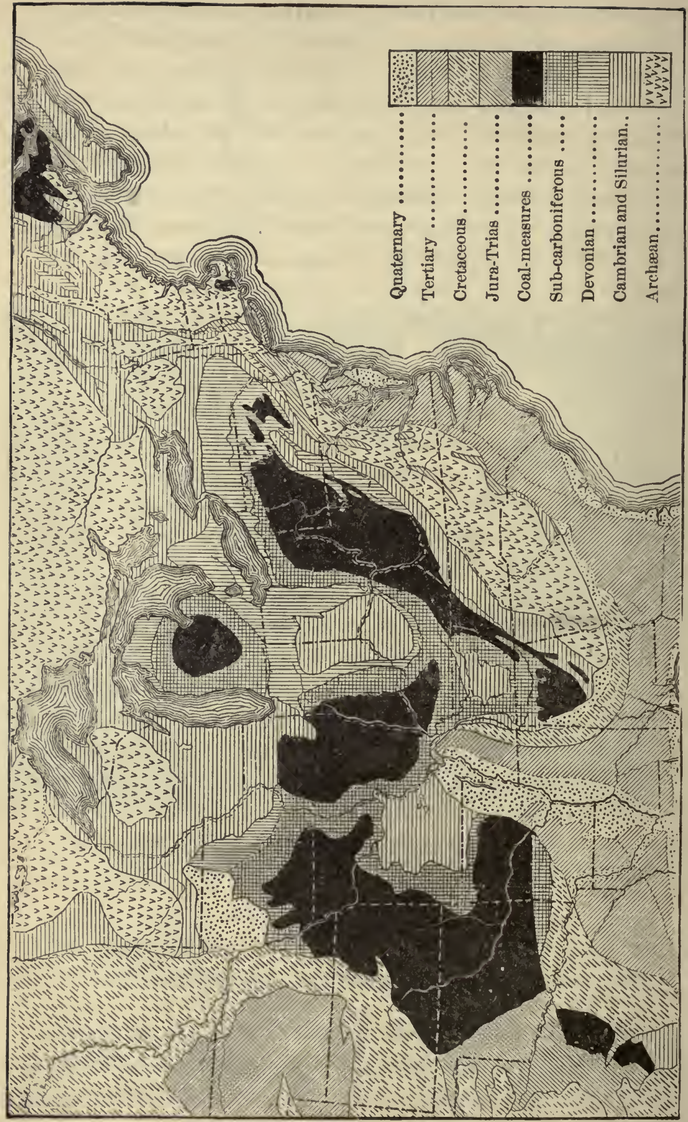
Quaternary
Tertiary
Cretaceous
Jura-Trias
Coal-measures
Sub-carboniferous
Devonian
Cambrian and Silurian
Archæan

FIG. 169.—Geological map of the eastern part of the United States.

Murchison. But they are far more perfectly represented in the United States.

Area.—It will be seen, by reference to the map, Fig. 169, that in the great Paleozoic basin these rocks form an irregular border to the Canadian and Blue Ridge Archæan areas. These borders were marginal sea-bottoms at the beginning of the Silurian times, and were elevated and reclaimed during and at the end of that time. There are many other smaller areas in the West, but these can not be defined.

Physical Geography.—We have already given this for the beginning of the age in the map, Fig. 168. For the *end* of the age, as just stated, we must add the Silurian area to the Archæan area. There was also at the end added a large island of Silurian sea-bottom in Ohio and Tennessee (see map, Fig. 169).

Subdivisions.—The Lower Paleozoic rocks are subdivided into—1. Primordial, or Cambrian; 2. Lower Silurian; 3. Upper Silurian; and these, again subdivided, as shown in the following schedule. We simply give these by name for reference, if necessary, but will treat of the whole Cambrian and Silurian together:

3. Upper Silurian.	Helderberg period
	Salina “
	Niagara “
2. Lower Silurian.	Trenton “
	Canada “
1. Cambrian, or Primordial.	Primordial “

Life-System.

We have already spoken of the apparent suddenness of the appearance of a somewhat diversified fauna in the Primordial, and accounted for it by the existence of a *lost interval.* Immediately after the Primordial the fullness of Paleozoic life became really wonderful. These early seas seem to have swarmed with a life as abundant as any now existing, but wholly different in species, in genera, and even in families, not only from any *now* living, but from those living in any other geological period. About 20,000 species are described from the Paleozoic, and of these at last one half, i. e., 10,000 species, are from the Silurian; and of course these are but a very small fraction of the number which actually existed. The number being so great, and the forms so unfamiliar to the pupil, it is impossible to do more than mention and figure a few of the most common and striking forms.

Plants.

The only kind of plants which are found so early are allied to sea-weeds.* As it is very difficult to determine these species from the very imperfect impressions of them left in the rocks, we shall call them by the general name of *Fucoids,* i. e., *fucus*-like plants, from their general resemblance to *Fucus* (tangle or kelp). We give a few

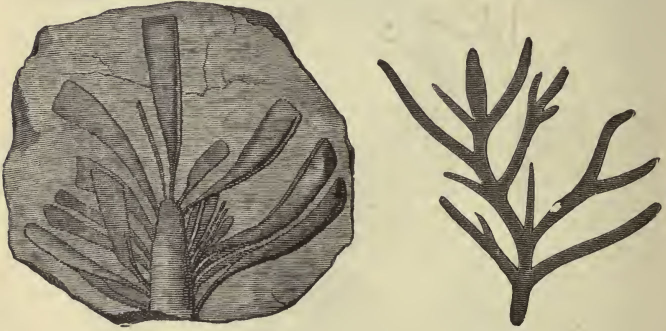

Fig. 170. Fig. 171.

Figs. 170, 171.—Silurian plants: 170. Sphenothallus angustifolius. 171. Buthotrephis gracilis.

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* A few small vascular cryptogams, allied to club-mosses, have been recently found in the Silurian.

(Figs. 170, 171), to show their general appearance. They belong to the lowest order of plants.

Animals.

These are far more numerous and diversified than the plants. We can mention only such as may be recognized even by the untrained eye.

Corals.—These are very abundant, and seem sometimes to have formed veritable *reefs*. There are three very characteristic forms, viz., *Cup*-corals (*Cyathophylloids,* Figs. 172, 173), *Honeycomb*-corals (*Favositids,* Fig. 174), and *Chain*-corals (*Halysitids,* Fig. 175). These are *all* characteristic of the *Paleozoic,* and the *last* characteristic of the *Silurian.* Now, any one can recognize these, especially the *Honeycomb* and *Chain* corals, and therefore when these are found any one may identify Paleozoic or even Silurian rocks.

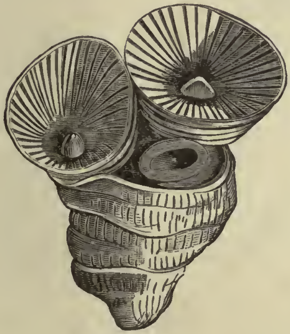

Fig. 172.

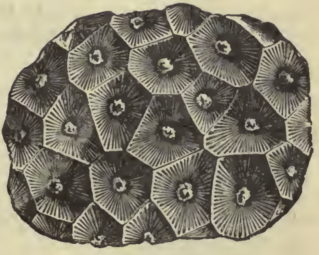

Fig. 173.

Figs. 172, 173.—Cyathophylloid corals : 172. Lonsdaleia floriformis. (After Nicholson.) 173. Strombodes pentagonus. (After Hall.)

Hydrozoa.—In still, sheltered bays, with fine mud-bottom, are *now* found, attached to sticks, logs, or shells, fine, feathery things, which look like finely dissected seaweed or sea-moss. They are, indeed, gathered by amateur collectors and pressed as sea-weeds. If they be examined with a lens, they are seen to be composed of hollow, branching stems, set on one or both sides with hollow cups, each containing an animal which, if kept undisturbed in sea-water, quickly spreads its thread-like tentacles. These are the *Hydrozoa* of the present day (Figs. 176, 177, 178). Now, in fine Silurian shales, which were once fine mud, are found impressions of animals probably similar to these. They are called *Graptolites.* Whatever they be, they are easily recognized and wholly

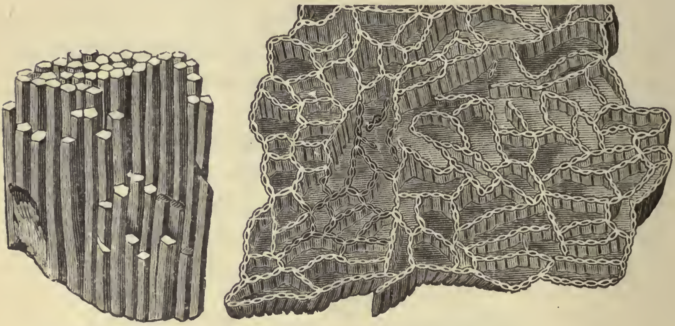

Fig. 174. Fig. 175.

Figs. 174, 175.—Favositid and halysitid corals : 174. Columnaria alveolata. (After Hall.) 175. Halysites catenulata. (After Hall.)

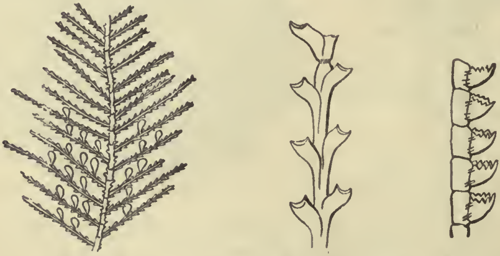

Fig. 176. Fig. 177. Fig. 178.

Figs. 176-178.—Living hydrozoa : 176 and 177. Sertularia. 178. Plumularia.

characteristic of Silurian, and any one may identify Silurian by means of them (Figs. 179, 180).

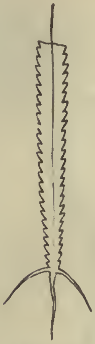

FIG. 179.

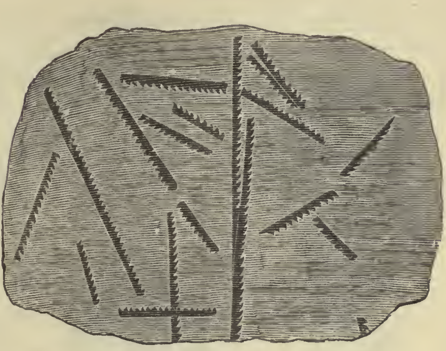

FIG. 180.

FIGS. 179, 180.—Silurian hydrozoa: 179. Diplograptus pristis. (After Nicholson.) 180. Graptolites Clintonensis. (After Hall.)

Echinoderms; Crinoids.—At the present time, if we leave out sea-cucumbers (*Holothurians*), because, having no shells, they are not preserved as fossils, Echinoderms are of three orders: 1. *Echinoids*, or sea-urchins; 2. *Asteroids,* or star-fishes; and, 3. *Crinoids.* The first two are *free*-moving, the last is *stemmed.* The first two are *now* very abundant, the last *rare.* But in Silurian times it was the reverse. The Echinoids did not exist at all, the Asteroids were rare, but the Crinoids extremely abundant, though, of course, of species and genera wholly different from any *now existing* (Fig. 181). It is well to observe that the crinoid is a lower form than the other two,

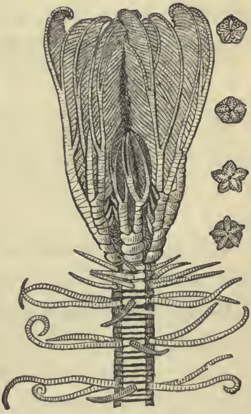

FIG. 181. — Living crinoid. Pentacrinus caput-medusæ.

as is shown by the fact that some free echinoderms have stems in the early stages of life, and afterward throw them off and become free.

Description of a Crinoid.—A crinoid has a pear-shaped body, containing the viscera, set upon a jointed stem, with mouth on the top of the pear, sometimes surrounded by many plumose arms (Fig. 182), sometimes with few simple arms (Fig. 183), sometimes with no arms at all (Fig. 184).

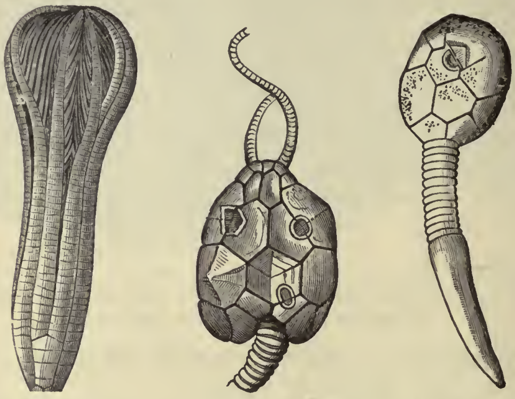

Fig. 182. Fig. 183. Fig. 184.

Figs. 182–184.—Silurian crinoids: 182. Heterocrinus simplex. (After Meek.) 183. Pleurocystitis squamosus. 184. Lepadocrinus Gebhardii.

Range in Time.—We have said that stemmed echinoderms or crinoids continue from earliest times until *now* (though the species and genera change repeatedly), but in *diminishing* numbers. The free echinoderms, on the contrary, have been constantly *increasing*. If, then, *A B* (Fig. 185) represent the course of geological time, and the parallelogram the equal abundance of echinoderms throughout, then the shaded portion below the diagonal would, in a general way, represent the constantly decreasing *stemmed*, and the unshaded space above the diagonal the constantly increasing *free* forms. But are there any characters by which we may easily recognize those peculiar to the Silurian? There are. Crinoids are subdivided into three main groups, viz.: 1. *Crinids,* or plumose-armed crinoids (Fig. 182); 2. *Blastids* (Fig. 242, page 316), or bud-crinoids; 3. *Cystids* (Figs. 183, 184), or bladder-crinoids. The crinids are not characteristic of Silurian, nor even of Paleozoic; the blastids are characteristic of Paleozoic, though not of Silurian; the cystids are characteristic of Silurian alone. This is represented by subdivisions of the shaded space in Fig. 185, in relation with the subdivision of the Paleozoic.

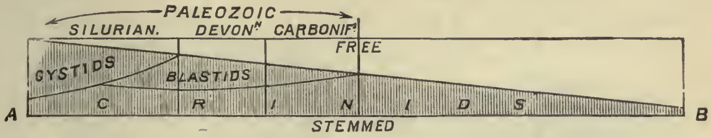

FIG. 185.—Diagram showing distribution in time of crinoids.

Mollusks; Brachiopods.—Bivalve shells are divided into two great groups, viz.: 1. Common bivalves (*Lamellibranchs*); and, 2. Lamp-shells, or *Brachiopods.* At present, the former are extremely abundant, and the latter rare. The reverse was true in Silurian times. The distribution in time of the two kinds may be roughly represented by the diagram (Fig. 186). Now. brachiopods are very different from, and much lower than, ordinary bivalves. Lamellibranchs have a right and left valve—right and left gills, etc.; in brachiopods the

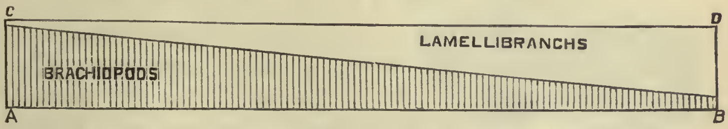

FIG. 186.—Diagram showing the general distribution, in time, of brachiopods and lamellibranchs.

valves are upper and lower, or a back-piece and a breastplate. The deeper and more projecting valve is the ventral. From the point of this valve comes out a fleshy cord, by which it is attached. It is this which gives it the name of lamp-shells, on account of its resemblance to the ancient lamp (Fig. 187). A large portion of the interior of the shell is occupied by long, spiral, fringed arms. It is these which give the name of brachiopod (arm-feet), although they are really gills. These are attached to complex, and sometimes spiral, bony pieces. Fig. 188 is a living brachiopod, showing structure. These shells are so extremely abundant in Paleozoic, especially Silurian rocks, that these rocks may often be identified by them. In Figs. 189, 190, we give two of the most common forms. Are there any characters by which Silurian brachiopods can be *easily* distinguished? Not by the *untrained eye.* Yet the square shouldered forms, like those figured here, are very characteristic of Paleozoic, though not of Silurian.

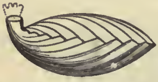

FIG. 187.—Living brachiopod. Side view.

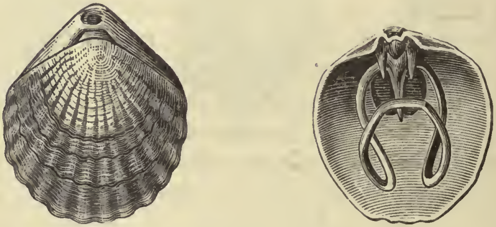

FIG. 188.—A living brachiopod Terebratula flavescens.

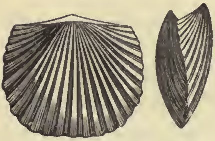

FIG. 189.—Silurian brachiopods; Orthis Davidsonii.

Lamellibranchs and Gasteropods.—The ordinary bivalve-shells (*Lamellibranchs*), and the univalves or gasteropods, like conchs, whelks, etc., are also found; but, in order to avoid confusing the mind with too many details, we shall pass over these and confine ourselves only to the most striking and characteristic forms.

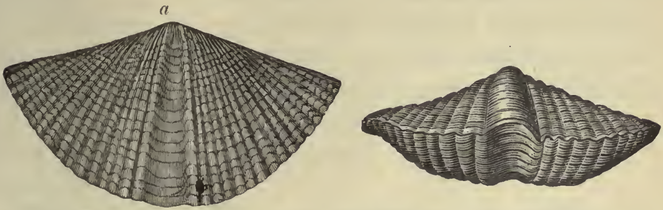

Fig. 190.—Silurian brachiopods: Spirifer Cumberlandiæ—*a*, ventral valve; *b*, suture.

Cephalopods; Orthoceratite.—The great class of Cephalopods, including now the squids, cuttle-fishes, and nautilus, were represented, in Silurian times, by a very remarkable family called *Orthoceratite* (straight-horn). The appropriateness of the name is recognized by the figures on page 282 (Figs. 192, 193).

Cephalopods now are, some of them, naked (squid and cuttle-fish), and some shelled (nautilus). When they have a shell, the shell is *chambered*. The animal lives in the outer part, and all the chambers are empty, full of air only, and connected with the animal by a membranous tube called the siphon-tube or siphuncle (Fig. 191). Now, at the present time, nearly all cephalopods are naked. Only one genus of the shelled kind remains, viz., the *Nautilus*. In Silurian times, and indeed long after, there were no naked ones. Only the shelled kinds existed. The naked

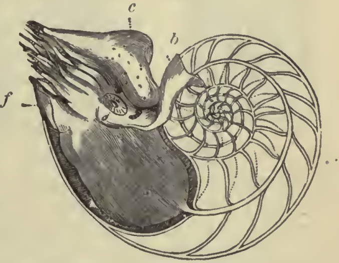

Fig. 191.—Pearly nautilus (Nautilus pompilius): *a*, mantle; *b*, its dorsal fold; *c*, hood; *o*, eye; *t*, tentacles; *f*, funnel.

kinds are the higher. Again, *now,* and throughout all later geological times, all the shelled cephalopods were coiled, like the nautilus. But Paleozoic, and especially Silurian times, were characterized by the abundance of long, tapering, *straight,* chambered shells. These are the *Orthoceratites.* They are entirely characteristic of Paleozoic, most abundant in the Silurian, and easily recognized by any one. We give figures of a few (Figs. 192–194), and an attempted restoration of the front part of the shell containing the animal.

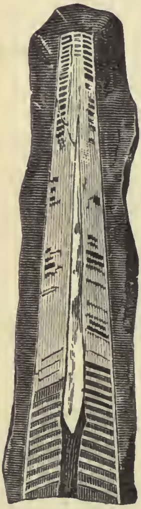

FIG. 192.

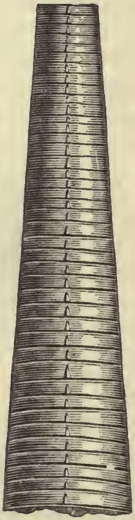

FIG. 193.

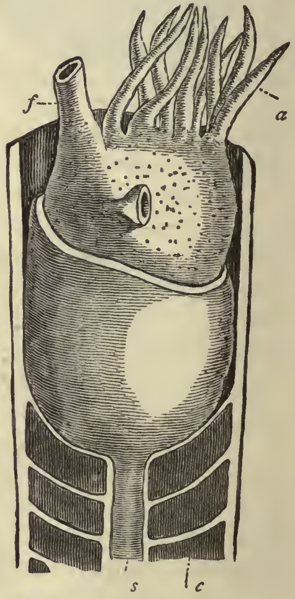

FIG. 194.

FIGS. 192–194.—Silurian cephalopods: 192. Orthoceras multicameratum. (After Hall.) 193. Orthoceras Duseri. (After Hall.) 194. Restoration of orthoceras, the shell being supposed to be divided vertically, and only its upper part being shown—*a*, arms; *f*, muscular tube ("funnel") by which water is expelled from the mantle-chamber; *c*, air-chambers; *s*, siphuncle. (After Nicholson.)

Orthoceratites were extremely abundant in Silurian times, and, in some cases, reached an enormous size. In the Silurian of the Western States, specimens have been found which were eight to ten inches in diameter, and over fifteen feet long. They were the most formidable animals of these early seas. They came in with the Primordial, reached their maximum in the Mid-Silurian, but continued through the Paleozoic, and then passed away forever.

Although the straight, chambered shells were by far the most abundant, yet the coiled kinds were also found.

Crustacea; Trilobites.—Passing over the *worms,* as being of less importance, although their borings, their tracks, their calcareous tubes, and even their teeth, have been found, we come at once to perhaps the most abundant and characteristic of all Paleozoic forms—*Trilobites.*

Description.—The shell of these curious creatures was convex above and flat or, more probably, *concave* below (Fig. 196). It was divided, like most crustaceans, into many movable joints, but several front joints were always consolidated to make a *buckler,* or head-shield, and usually, but not always, several hind joints were consolidated to form a *pygidium,* or tail-shield. Longitudi-

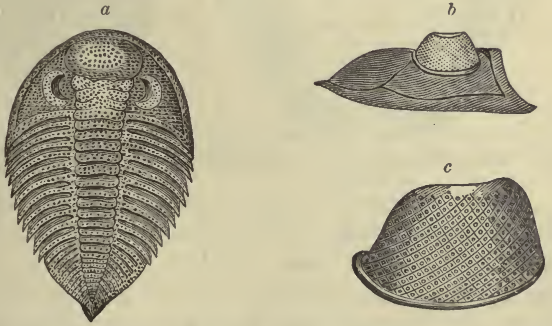

Fig. 195.—Structure of the eye of trilobites: *a*, Dalmania pleuropteryx; *b*, eye slightly magnified; *c*, eye more highly magnified. (After Hall.)

nally, the upper surface of the shell was divided by two depressions into *three lobes* (hence the name). On each side of the head-shield, in position exactly as in the *king-crab* (*Limulus*), were placed the eyes; and, strange to say, we find the eye, even at this early time, already a complex structure well adapted to form an image (Fig. 195). Recently have been discovered jointed legs, *l, l,* each with two branches, one for crawling and one for swimming; and also slender, many-jointed antennæ, *a, a,* like many crustaceans of the present day (Fig. 196). They had the habit, which many crustaceans now have, of folding themselves so as to bring head and tail together in front, as shown in Fig. 199. In the following figures (Figs. 197, 198) we give some examples of Silurian Trilobites.

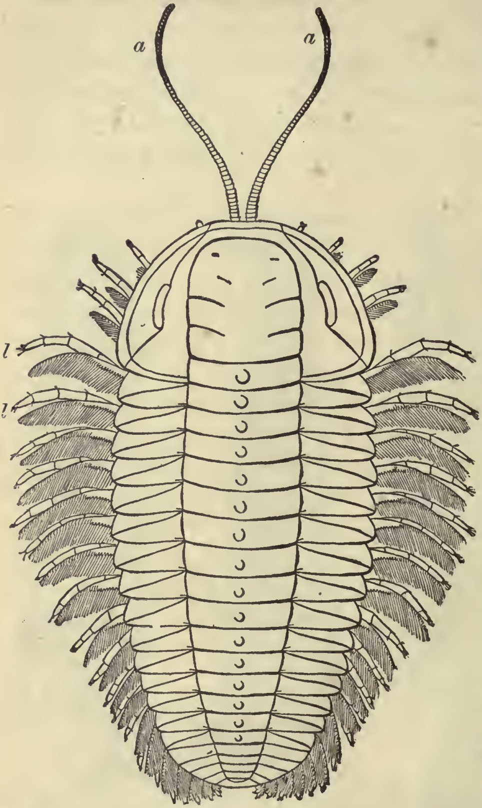

Fig. 196.—Restoration of upper side of calymene. (After Beecher.)

Trilobites are found in great numbers, of almost infinite variety of form and markings, and of size varying from a fraction of an inch to twenty inches in length (Fig. 197).

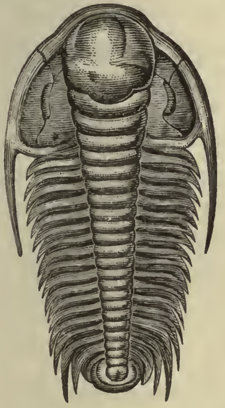

Fig. 197.

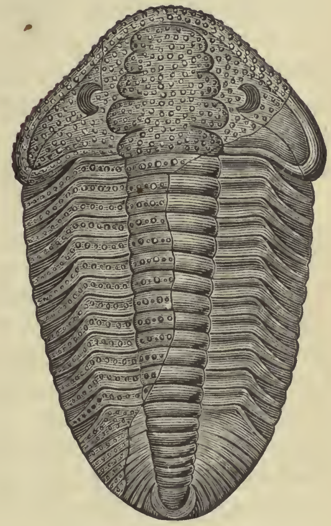

Fig. 198.

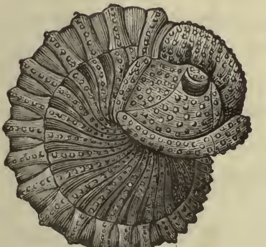

Fig. 199.

Figs. 197-199.—Silurian trilobites: 197. Paradoxides Harlani, × ⅛ (after Rogers). American. 198. Calymene Blumenbachii. 199. Same in folded condition.

They come in with the earliest Primordial, reach their maximum in Mid-Silurian, but continue through Palæozoic, and pass out forever. They are, therefore, entirely characteristic of the Paleozoic, and especially abundant in Silurian. Although belonging to a distinct order, different from any now living, yet they were more nearly allied to the horseshoe crab (*Limulus*) than anything else. They are so abundant, so well preserved, and so easily recognized, even by the untrained eye, that they are a very valuable means of identifying Paleozoic, and especially Silurian, strata.

Anticipations of the Next Age.—The most highly organized and most powerful animals of Silurian times were undoubtedly the *Orthoceratites* and the *Trilobites.* The Orthoceratites especially were the tyrants and scavengers of those early seas; yet, in the uppermost Silurian are found a few insects, scorpions, and cockroaches, and a few *fishes* similar to forms far more abundant in Devonian. It is better, therefore, to regard these as anticipations.

SECTION III.—DEVONIAN SYSTEM. THE AGE OF FISHES.

Rock-System; Name.—The name Devonian was given to these rocks because first studied with success in Devonshire. In Scotland they were called Old Red Sandstone, by Hugh Miller. In England it is often unconformable on the Silurian, but in the Eastern United States, as already stated, the Paleozoics are conformable throughout. Nevertheless, even in America there is a great change of life-forms at this point of time; and, moreover, the first introduction here of a new reigning class—viz., fishes, and a new great department of animals—viz., Vertebrata, or backboned animals, is a prodigious advance, and entitles this to be considered a distinct age. It is well to note, however, that some anticipations of this great advance are found in the Silurian.

Area in the United States.—By examining the map on page 272, it will be seen that in general the Devonian rocks border on the Silurian area on the south and west and extend far south in the middle region. In the Rocky Mountain region there are considerable areas of Devonian, but their limits are too little known to be described.

Physical Geography.—The land during early Devonian times was the Archæan area, increased by the addition of the Cambrian and Silurian area, the Devonian area being then of course sea-bottom. In the middle of the Devonian Sea there was a large island of Silurian rocks occupying what is now mid-Ohio and running down through mid-Tennessee. At the end of the Devonian, the Devonian area was exposed as land and added to that previously existing.

Subdivisions.—The American Devonian is subdivided into at least four groups of strata representing four periods, as shown in the schedule. We shall, however, neglect these subdivisions in our general account of the life-system:

4. Chemung period.
3. Hamilton period.
2. Corniferous period.
1. Oriskany.

Life-System of Devonian.—Plants.

In Silurian times, with the exception of a very few small vascular cryptogams allied to club-moss, we found nothing higher than fucoids. In addition to these, now, for the first time, land-plants become conspicuous. Here, for the first time, we have a true *forest* vegetation. The character of the trees of this first forest is a question of the highest interest. The Devonian forests consisted of the *highest* cryptogams, *vascular* cryptogams, and the *lowest* phenogams, *Gymnosperms*. More explicitly, there were *Ferns, Lepidodendrids,* and *Sigillarids* (gigantic club-mosses), and *Calamites* (gigantic *Equisetæ*) among vascular cryptogams: and *Conifers* allied to the yews among gymnospermous phenogams.

We shall not describe these now, since they are all much more abundantly represented in the Carboniferous.

We shall therefore dismiss them for the present with one or two remarks.

1. In Nova Scotia, in direct connection with the plant-beds, have also been found many *fossil forest-grounds.* These are marked by dark seams with stumps and roots in place just as the trees grew. In some cases, also, thin seams of *coal* lie upon the forest-grounds. Thus, therefore, we have here in the Devonian an anticipation not only of coal vegetation, but also of the conditions necessary for the formation and preservation of coal.

2. We have here a somewhat sudden appearance of land-plants, as if they came without progenitors. But we must remember that we have a feeble beginning of land-plants in the Silurian. It seems probable that in the Devonian we had more favorable conditions, and therefore a rapid development of new forms.

Animals.

If we bear in mind what we said about Silurian animals, it will be necessary here only to note the great changes, i. e., what *old* forms pass out, what *new* forms come in, and what *advances* are made in the progress of life, dwelling only on the great characteristic of the age, viz., the *fishes.*

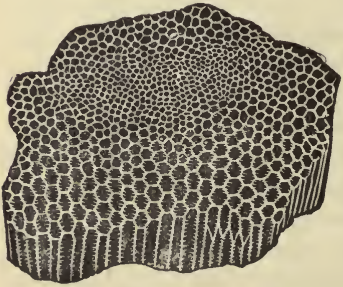

FIG. 200.

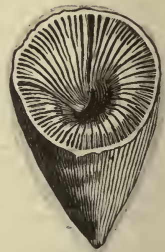

FIG. 201.

FIGS. 200, 201.—Devonian corals : 200. Favosites hemispherica. 201. Zaphrentis Wortheni. (After Meek.)

Radiates.—Among *corals*, the characteristic Silurian chain-corals (*Halysitids*) are gone, but the other two forms remain, with different species (Figs. 200, 201). The graptolites are gone, as also the *Cystidean* crinoids, but the blastids or bud-crinoids are now far more abundant, though they reach their maximum only in the Carboniferous (Fig. 242, page 316).

Bivalves and Univalves.—Brachiopods still continue in great numbers, of the characteristic Paleozoic, square-shouldered forms (Fig. 202), and both Lamellibranchs and Gasteropods (univalves) are now more abundant. It is well to note that fresh-water and land forms are now for the first time introduced.

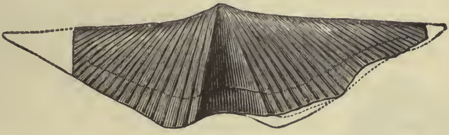

Fig. 202.

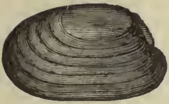

Fig. 203.

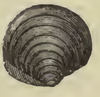

Fig. 204.

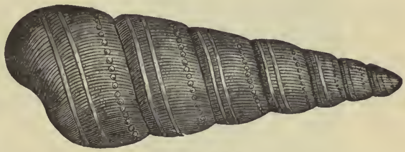

Fig. 205.

Figs. 202-205.—Devonian brachiopods. 202. Spirifer perextensus. (After Meek.) Devonian lamellibranchs and gasteropods: 203. Ctenopistha antiqua. (After Meek.) 204. Lucina Ohioensis. (After Meek.) 205. Orthonema Newberryi. (After Meek.)

Cephalopods.—The Orthoceratites still continue in Devonian times, though in greatly diminished number and size; but we note here a great advance in the introduction of a *new* form characteristic of this and the Carboniferous, viz., the *Goniatites* (angled stones), so called because the *suture* or junction of the partition with the shell is angled instead of simple (see Fig. 246, page

317). It should be remembered that this is the first introduction of a family (*Ammonite* family) which in Mesozoic times became extremely abundant. The family is characterized by the *dorsal position of the siphon-tube and the complexity of the suture.* We shall hereafter trace the increasing complexity of the suture. It only begins in the Goniatite.

Crustacea.—Trilobites still continue under new forms (Fig. 206), but in greatly diminished number and size. They have passed their prime.

Insects.—Insects are *now,* and at all previous geological times have been, closely related to land vegetation. The first conspicuous land vegetation is found in the Devonian, and in connection with this vegetation are found also the first known insects (Fig. 207). These first insects were most nearly allied to cockroaches and dragonflies—in fact, a connecting link between these orders.

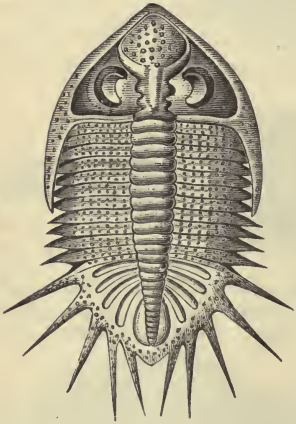

Fig. 206.

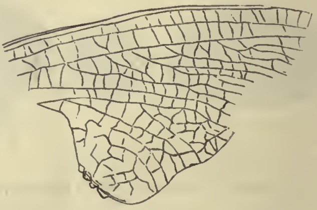

Fig. 207.

Figs. 206, 207.—206. Devonian trilobite and insect: Dalmania punctata; Europe. 207. Wing of platephemera antiqua; Devonian, America. (After Dawson.)

In some a *chirping* organ has been found. This shows that an auditory apparatus was already developed.

Although these first known insects are among the lower orders of the class, and also are connecting links between two such lower orders, yet their somewhat perfect development indicates that we must look for the very first insects still lower, i. e., in the Upper Silurian. They have been recently found there.

Fishes.—The introduction of fishes must be regarded as a great step in the progress of life, for it is the beginning not only of a new and higher class, but of a new great department and the highest, viz., Vertebrata. They commenced first in the lowest Devonian or perhaps even in the uppermost Silurian, few in numbers, small in size, and of strange, un-fish-like forms, but soon developed in size and numbers until these early seas swarmed with them, and they quickly became the rulers of the age. The previous rulers, Orthoceratites and Trilobites, therefore diminish in number and size, and thus *seek safety in subordination.* As examples of the great size of Devonian fishes, we mention a few. The *Onchyodus* (claw-tooth) had jaws eighteen inches long, armed with teeth two or more inches long; the *Dinichthys* (huge fish) was fifteen to eighteen feet long, three feet thick, and had jaws two feet long, armed with curious blade-like teeth. These are from America. The *Asterolepis* (star-scale) of Europe is believed to have been twenty feet long, and of proportionate dimensions.

We must not imagine, however, that these fishes were at all like most common fishes of the present day. Neglecting some rare and unusual kinds, fishes may be divided into three great orders, viz., 1. *Teleosts* (complete bone); 2. *Ganoids* (shining); and 3. *Elasmobranchs* (plate-gills). The Teleosts include all the ordinary fishes: examples of Ganoids are found in gar-fish and sturgeon; of Elasmobranchs, in sharks, skates, and rays. At the present time, nine-tenths of all fishes are Teleosts, but in Devonian times all the fishes were Ganoids and sharks, especially the former, though differing in species and genera from Ganoids and sharks of the present day. But we must give some figures of these strange Devonian fishes before discussing their affinities any further.

Description of Some Devonian Fishes.—The *Cephalaspis* (head-shield, Fig. 208) was a small fish, of very curious shape, with mouth beneath the head-shield. The *Pterichthys* (winged fish, Fig. 209) was so completely incased in bony plates that it must have swum mainly by means of its wing-like anterior fins. The mouth was also beneath. The *Coccosteus* (berry-bone, Fig. 210) was covered with bony plates in front parts, but the tail was usable for locomotion. The *Dinichthys* (Fig. 211) was a

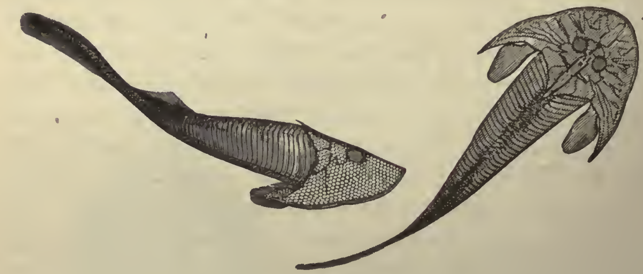

Fig 208.

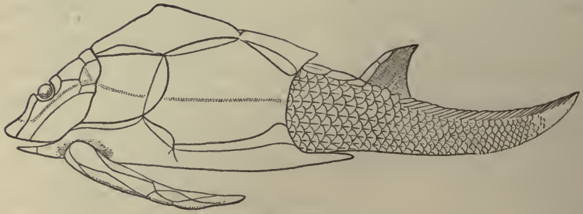

Fig. 209.

Figs. 208, 209.—Devonian fishes—Placoderms : 208. Cephalaspis Lyelli. (After Nicholson.) 209. Pterichthys cornutus. (After Nicholson.)

huge fish, sometimes eighteen to twenty feet long, very abundant in the Devonian of Ohio. Like the Coccosteus, the anterior tail was covered with broad, bony plates.

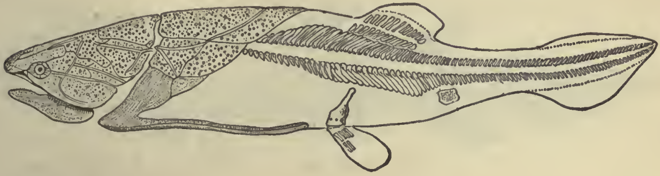

FIG. 210.

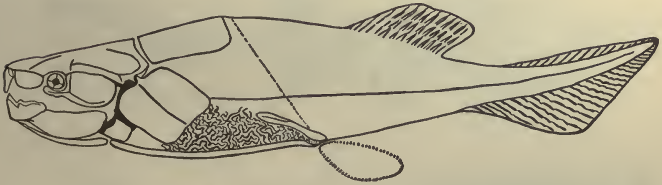

FIG. 211.

FIGS. 210, 211.—Devonian fishes—Placoderms: 210. Coccosteus decipiens. (After Owen.) 211. Dinichthys. (After Dean.)

The *Osteolepis* (bony scale, Fig. 212) was covered with a complete coat-of-mail of rhomboidal bony scales, like the gar-fish and polypterus (Fig. 217) of the present day. The *Diplacanthus* (double spine, Fig. 213) is more fish-like in form, but is also covered with rhomboidal bony scales. We draw attention to the shape of its tail. All these are Ganoids. The sharks, on account of their cartilaginous skeleton and imperfect scales, are known chiefly by their bony spines and by their teeth. A restoration of a Devonian shark from Ohio is given in Fig. 214.

By examination of the figures, it is seen that Devonian Ganoids are, some of them, wholly or partly covered with large, immovable, bony plates (Figs. 208–211); others with smaller, rhomboidal, bony scales (Figs. 212, 213). The former are called Placo-ganoids (plate-ganoids), or

Placoderms (plate-skin); the latter, Lepido-ganoids (scale-ganoids). Now, the Placo-ganoids are characteristic of the Devonian, and the largest Devonian fishes, such as the *Dinichthys* and *Asterolepis*, belong to this family. The Lepido-ganoids continued after the Devonian, and are still represented by gar-fishes, etc. The sharks of the Devonian belong, all of them, to a family now almost extinct, called Cestracionts (*sharp tool,* referring to the spine).

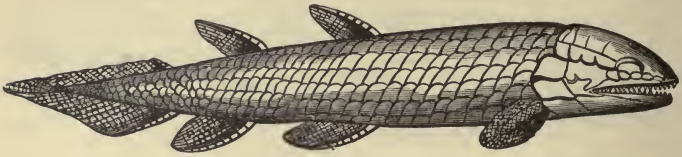

FIG. 212.

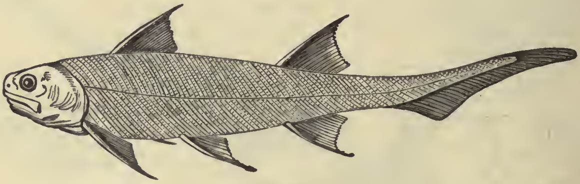

FIG. 213.

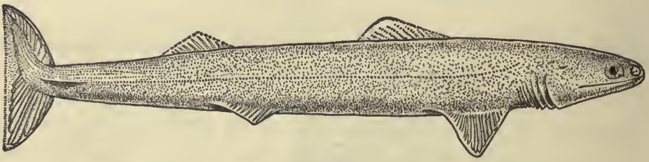

FIG. 214.

FIGS. 212–214.—Devonian fishes—Lepido-ganoids: 212. Osteolepis. (After Nicholson.) 213. Diplacanthus gracilis. (After Nicholson.) Sharks: 214. Ctenacanthus vetustus, spine reduced. (After Newberry.)

Affinities of Devonian Fishes.—There are no living representatives of the Placo-ganoids, but there are such of the Lepido-ganoids. We herewith give figures of those modern fishes which are most like the Devonian fishes.

The first is an Australian fresh-water fish, the recently discovered *Ceratodus* (horn-tooth) (Fig. 215). The second, *Lepidosiren* (scale-siren), is a very curious animal, intermediate between fish and reptile, found in South America and Africa (Fig. 216). The third is the gar-fish, *Polypterus* (many fins), from the Nile (Fig. 217). The fourth is the only living representative of cestraciont sharks—the Cestracion of Australian seas (Fig. 218).

Bearing on Evolution.—It is a curious fact that these fishes, which are most nearly allied to Devonian fishes, are by no means low in the scale, but, on the contrary, are, in some respects at least, very high. But one thing is very noteworthy, viz., that they all have amphibian characters united with fish characters—they are all *connecting links between fish and amphibian.* For example, it is seen that the vertebral column in these, and still more in their Devonian allies, runs far into, often to the end of, the tail-fin. *The tail-fin is vertebrated.* The tail vertèbræ are finned on the sides. This is universal in Devonian fishes. Again,

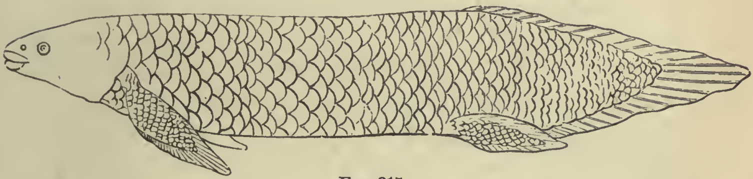

FIG. 215.

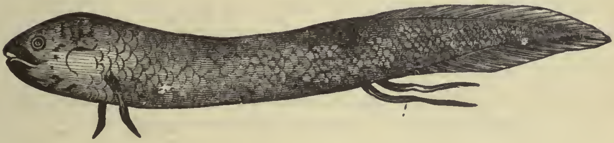

FIG. 216.

FIGS. 215, 216.—Nearest living allies of Devonian fishes: 215. Ceratodus Fosterii, × $\frac{1}{12}$. (After Gunther.) 216. Lepidosiren.

it is observed that in many the paired fins are curiously formed—they are a sort of limbs *fringed* with fin. Now, a large number of Devonian fishes (Fig. 212) have this style of paired fins. In the third place, all the living

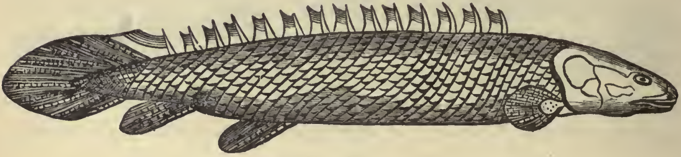

FIG. 217.

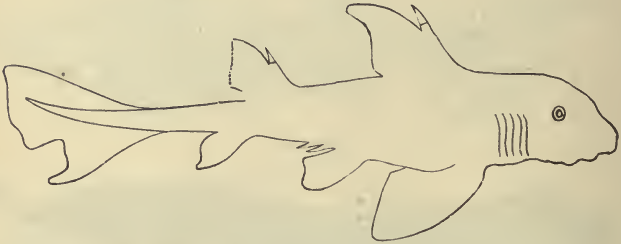

FIG. 218.

FIGS. 217, 218.—Nearest living allies of Devonian fishes: 217. Polypterus. 218. Cestracion Phillippi (a living cestraciont from Australia).

Ganoids given above (Figs. 215, 217) have a more or less perfect lung, and supplement their water-breathing with air-breathing, in the manner of some amphibian reptiles. It is almost certain that the same was true of Devonian Ganoids. And yet, with all these reptilian characters, all Devonian fishes had cartilaginous skeletons like the embryos of Teleosts.

We wish now to take advantage of these facts to announce a very general law. The first introduced examples of any family, order, or class, are not typical forms of that family, order, or class, but intermediate forms or connecting links with other families, orders, etc. From such intermediate forms or connecting links have been afterward developed the more typical forms. To illustrate: The first fishes were not typical fishes, but connecting links between fish and amphibian, and from this intermediate form, as from a trunk, true fishes and amphibians were afterward separated and developed as branches. Such intermediate forms we shall hereafter call *generalized forms,* and the more typical forms into which they seem to be afterward developed, *specialized forms.* We shall find many illustrations of this law as we proceed.

Apparent Suddenness of the Appearance of Fishes.—At a certain time fishes seem suddenly to appear, as if they came without progenitors. But we must remember that the very lowest forms of fishes have neither bony skeleton nor scales, and their remains are not likely to be preserved. We may yet find evidences of such far down in the Silurian. Nevertheless, there can be little doubt that conditions were favorable for the development of fishes about the beginning of the Devonian, and therefore the steps of development were exceptionally rapid at that time.

SECTION IV.—CARBONIFEROUS SYSTEM. AGE OF ACROGENS AND AMPHIBIANS.

Subdivisions.—The Carboniferous age is subdivided into three periods: 1. *Sub-carboniferous;* 2. *Carboniferous* proper, or *coal-measures;* 3. *Permian.* The first may be regarded as the preparation, the second the culmination, and the third the transition to the Mesozoic. The whole carboniferous strata in Nova Scotia is 16,000 feet thick, in Wales 14,000 feet, in Pennsylvania 9,000 feet.

The sub-carboniferous strata are mostly limestones; those of the coal-measures mostly, though not wholly, sands and clays. The sub-carboniferous are marine deposits, the coal-measures mainly fresh-water deposits, The fossils of the former are, therefore, marine animals; those of the latter mainly land-plants, and fresh-water and land animals. In both Europe and America the sub-carboniferous underlies the coal-measures and outcrops around, and thus forms a penumbral margin about the black areas representing coal-fields on geological maps (see Fig. 169).

After this brief comparison and contrast, we shall now concentrate our attention on the coal-measures, because all the characteristics of the Carboniferous age culminate there. In speaking of the fauna, however, we shall take the two together. The Permian will be treated as a transition to the Mesozoic.

Carboniferous Proper—Rock-system, or Coal-Measures.

Name.—The Carboniferous *period* is but one of three periods of the Carboniferous age. The Carboniferous age is but one of the three ages of the Paleozoic era. The Paleozoic era is but one of the four great eras, exclusive of the present. The Carboniferous period, therefore, is but a small fraction, certainly not more than one twentieth to one thirtieth of the recorded history of the earth. Yet, during this period were accumulated, and in its strata were preserved, and are now found, nine tenths of all the coal used by man. The name *carboniferous*, for the period, and *coal-measures*, for the strata, is surely, therefore, appropriate.

Thickness of the Strata.—Although so small a portion of the whole strata of the earth, these coal-measures are often, locally, of great thickness. In Nova Scotia the coal-measures, exclusive of the sub-carboniferous, are 14,000 feet thick, in Wales 12,000, in Arkansas 25,000 (Branner), and in West Virginia 5,000.

Mode of Occurrence of Coal.—Such being the thickness, it is evident that but a small portion is *coal*. In fact, the coal-measures consist of alternations of sandstones, shales, and limestones, like other formations ; but interbedded with these are also *seams of coal* and *beds of iron-ore.* These five kinds of strata alternate with each other, and are each repeated many times, but without any regular order, as shown in Fig. 219, which is an ideal column from a coal-field. Thus, the strata of a coal-field may be likened to a ream of sheets of five colors, but arranged without order. Only this may be said, that beneath every coal-seam there is always a thin layer of clay, called the *under-clay,* and above is usually, but not always, a shale, called the *black shale* or *roof-shale.* It is a rich coal-measure in which we find one foot of coal for fifty feet of rock.

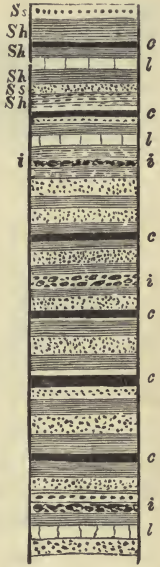

Fig. 219.—Ideal section, showing alternation of different kinds of strata : *Ss*, sandstone ; *Sh*, shale ; *l*, limestone ; *i*, iron ; and *c*, coal.

Subsequent Changes.—The strata of coal-measures, like all other strata, were horizontal when first laid down ; but, like other strata also, they have been elevated, and tilted and folded and crumpled and broken and faulted, especially in mountain-regions. And in all cases, whether horizontal (Fig. 221) or folded (Fig. 220), they have been largely carried away by erosion, and the strata left outcropping on the surface (Figs. 220, 221), and often in isolated patches. Since coal-seams, like other strata, are broken and faulted, it is very important to remember the law of slip mentioned on page 232.

Thickness and Number of Seams.—The thickness of seams varies from a few inches to many yards. The mammoth seam of Pennsylvania is over one hundred feet thick. The best thickness for easy working is about six to ten feet. The number of seams in a single field may be a hundred or more, and their aggregate thickness may be, in some cases, one hundred to one hundred and fifty feet of solid coal.

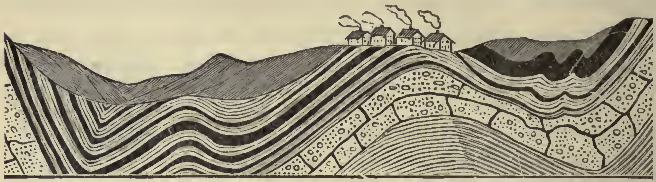

FIG. 220.—Panther Creek and Summit Hill traverse. (After Daddow.)

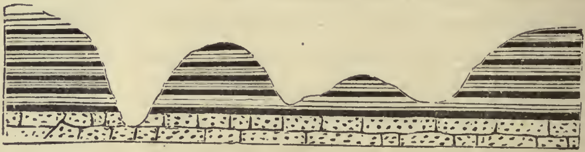

FIG. 221.—Illinois coal-field. (After Daddow.)

Coal-Fields of the United States.—In the map on page 272 the coal-fields of the United States belonging to this period are represented in black. It is seen that there are four of these: 1. *The Appalachian coal-field,* probably the richest in the world. In a general way it may be said to cover the western slope of the Appalachian chain from Pennsylvania southward. It covers an area of 60,000 square miles. 2. *The central coal-field.* This covers nearly the whole of Illinois, the western portion of Indiana, and northwestern Kentucky, and its area is 47,000 square miles. 3. *The great Western coal-field.* This covers southern Iowa, northwestern Missouri, eastern Kansas, the Indian Territory, western Arkansas, and northern Texas. Its area is no less than 78,000 square miles. 4. *The Michigan coal-field.* This occupies an area of

6,700 square miles in the center of the Michigan Peninsula. Besides these, there is a small area of coal of little value in Rhode Island, and a fine coal-field of 18,000 square miles accessible to us in Nova Scotia. Of the 192,200 square miles of coal within the limits of the United States, 120,000 square miles are estimated as workable. It may be said with confidence that there is no country in the world so liberally supplied with this great agent of modern civilization as our own.

Appalachian	60,000
Central	47,000
Great Western	78,000
Michigan	6,700
Rhode Island	500
	192,200
Nova Scotia	18,000
Total	210,200

Origin of Coal and of its Varieties.

There can be no doubt that coal is of *vegetable origin.* All portions of a coal-seam, even the most structureless to the naked eye, when properly prepared, reveal their vegetable structure to the microscope (Figs. 222, 223).

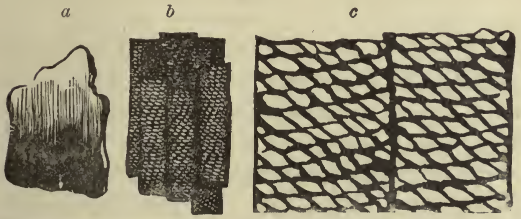

FIG. 222.—Section of anthracite: *a*, natural size; *b* and *c*, magnified. (After Bailey.)

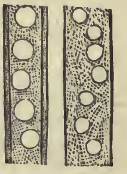

FIG. 223.—Vegetable structure in coal. (After Dawson.)

Varieties of Coal.—Assuming the vegetable origin of coal, how do we account for the varieties? These varieties are of three kinds: 1. Varieties depending on degrees of purity; 2. On degrees of bituminization; 3. On the relative proportion of fixed and volatile matter.

1. **Varieties depending on Degrees of Purity.**—Coal consists of combustible and incombustible matter, or ash. The combustible matter is organic, the ash mineral. Now, the relative proportion of these varies in every degree. The purest coal may contain only 1 to 2 per cent. of ash; but coal may contain 5 to 10 per cent., 20 to 30 per cent., 50 to 60 per cent., and so on to 90, 95, 99 per cent. ash. If a coal contains not more than 5 per cent. ash, it is probably pure, i. e., its ash is wholly due to ash of original vegetable matter; but if it contains more than 10 per cent., it is certainly impure, the excess being due to mud deposited with the vegetable matter.

2. **Varieties depending on the Degrees of Bituminization.**—Coal may be pure, and yet imperfectly bituminized. Such are *lignites, brown coal,* and the like. This depends mainly on age, the oldest coals being most completely changed.

3. **Varieties depending on the Relative Proportion of Fixed and Volatile Matter.**—In pure and perfect coal there are still varieties depending on the relative amount of fixed carbon and volatile hydrocarbon, and it is mainly this which produces the varieties of good coal, and determines its various uses. If the coal contains only 5 to 10 per cent. volatile matter, it is called *anthracite,* which is a hard, lustrous variety, breaking with a conchoidal fracture, and burning with very little blaze, but great heat. If it contains 15 to 20 per cent. of volatile matter, it is called semi-bituminous, or *steam-coal,* because of its excellence in rapid formation of steam. It burns with a long blaze, but does not *cake.* If it contains 30 to 40 per cent., it is ordinary bituminous caking coal; if 50 per cent., or more, highly bituminous, fat, or fusing coal. In this series we might well put graphite, or plumbago, above anthracite; for graphite consists of carbon

without any volatile matter, and, although it is not called coal, because incombustible, yet it is but the last term in the above series of varieties.

Cause of these Varieties.—Vegetable matter decaying out of contact with air, i. e., beneath water or buried in mud, loses a large portion of its material in the form of gases (CO_2, CH_4, and H_2O). These (CO_2 and CH_4) are the gases which escape in bubbles when we stir the bottom of a stagnant pool in which plants are growing. They are also the gases which are constantly escaping in every coal-mine, and form the deadly *choke-damp* and the still more dreaded *fire-damp* of the mines. Now, the relative proportion in which these are given off determines most of the above varieties.

Anthracite and graphite may be regarded as metamorphic coals. The reasons for so thinking are mainly the following: 1. Coal is often made locally anthracitic by a lava-flow or dike. 2. In the same coal-field, wherever the strata are crumpled and metamorphic, as in eastern Pennsylvania, the coals are anthracitic; and where the strata are flat-lying and unchanged, as in Ohio, the coal is bituminous.

Plants of the Coal.

In no other strata have the remains of plants been found in so great abundance and variety as in the coal-measures. We could expect nothing else when we remember that a coal-seam is a mass of vegetable matter, and that, on account of their economic value, these seams are continually explored. The remains of plants are found in the form of leaves, flattened stems and branches, and sometimes fruits, in connection with the black *roof-shale;* and as stumps and roots, in connection with the *under-clay* or floor of the seams.

Principal Kinds.—The plants belong mainly to four or five great orders, viz., *Conifers* and probably *Cycads,* among gymnosperms, and *Ferns*, *Club-mosses*, and *Equisetæ*, among vascular cryptogams. These orders were anticipated in the Devonian, but culminate here.

1. **Conifers and Cycads.**—These are found as leafy

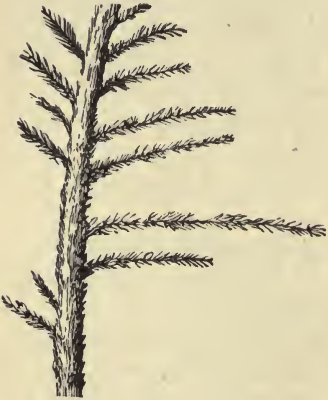

FIG. 224.—Araucarites gracilis, reduced. (After Dawson.)

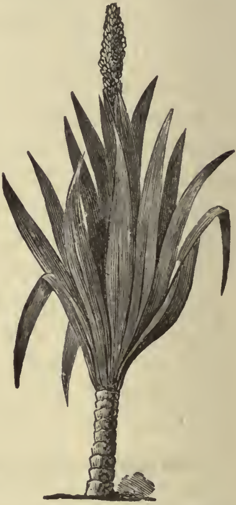

FIG. 225.—Cordaites. (Restored by Dawson.)

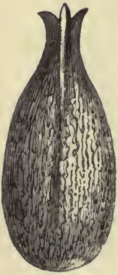

FIG. 226.

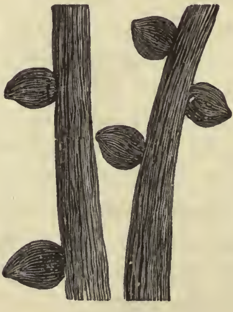

FIG. 227.

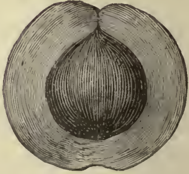

FIG. 228.

FIGS. 226–228.—Fruits of coal-plants, probably conifers : Cardiocarpon. (After Newberry and Dawson.)

branches (Fig. 224), as scattered leaves, like those in the restored tree (Fig. 225), as nut-like fruits (Figs. 226–228), near the top of the coal-seams, and sometimes as drift-logs in the sandstones, interstratified with the coal. The trunks are known to be conifers by the microscopic structure of the wood, the cells of which are marked with circular disks on longitudinal section (Fig. 229), and on cross-section the wood is destitute of pores.

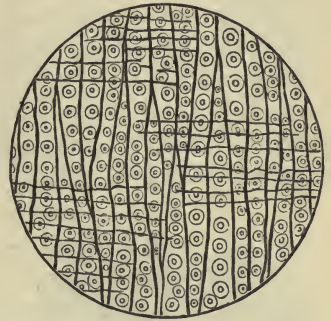

FIG. 229.—Longitudinal section of wood of a living conifer, magnified.

Now, what kind of conifers have such leaves and fruit as these? None but the yew family. All of these have plum-like fruit with nut-like seeds, and many of them have broad leaves (Fig. 230). The cordaites (Fig. 225) has been found with trunk sixty to seventy feet

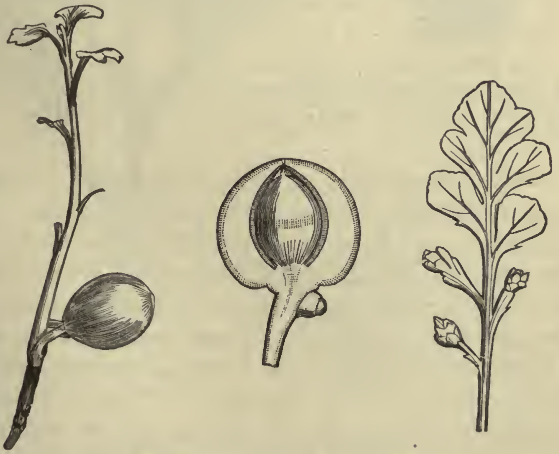

FIG. 230.—Living broad-leaved yews.

long, crowned with broad leaves, and with a spike of fruit. It is probably a *Cycad*, or else a broad-leaved conifer like the ginkgo.

2. **Ferns.**—These are the most abundant, but not the largest, plants of the coal. About one half of all the known species of coal-plants are ferns. They are often beautifully preserved, large, complex fronds spread out and pressed, as if between the leaves of a botanist's herbarium, with even the microscopic veining of leaflets visible. They are known to be ferns—1. By their large, complex fonds (Fig. 231). 2. By the peculiar veining of the leaves, characteristic of ferns (Fig. 232). 3. By the rows of spore-cases on the under surface of the leaves (Fig. 234). 4. In the case of tree-ferns, by ragged, ovoid marks, leaf-scars left by the fallen fronds. We give a few figures of ferns of the American and French coal-measures.

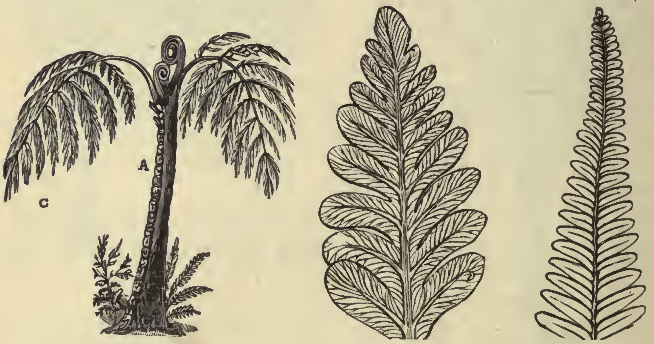

FIG. 231. FIG. 232. FIG. 233.

FIGS. 231–233.—Coal-ferns: 231. Megaphyton, a coal-fern restored. (After Dawson.) 232. Callipteris Sullivanti. (After Lesquereux.) 233. Pecopteris Strongii. (After Lesquereux.)

The remaining orders, viz., *Lycopods* (or club-mosses) and *Equisetæ* (horse-tails or scouring-rushes), are still more important, for two reasons: 1. They formed the principal mass of the coal. 2. They were very remarkable examples of generalized types or connecting links, and

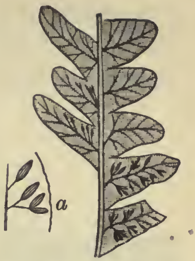

FIG. 234.—Dactylotheca dentata. (After Zeiler.) *a*, spore case enlarged.

possess a high interest on that account. We shall treat of them under three heads, viz., *Lepidodendrids, Sigillarids,* and *Calamites.*

1. **Lepidodendrids.**—Every part of these has been found—roots, stems, branches clothed with leaves and tipped with fruit. They may be restored, therefore, with some degree of confidence. Imagine, then, a trunk two, three, or even four feet in diameter at its base where it joins the wide-spreading roots; marked with regular rhomboidal figures, which are the leaf-scars (Fig. 236); branching widely, but not profusely; the great branches, clothed with scale-like or needle-like leaves, stretching aloft, like uplifted hairy arms, to the height of fifty or sixty feet, and terminating in scaly cones like club-mosses. The most common findings are flattened stems with beautiful rhomboidal markings (Fig. 236), looking much like rhomboidal scales of a ganoid fish; hence the name Lepidodendron, or scale-tree.

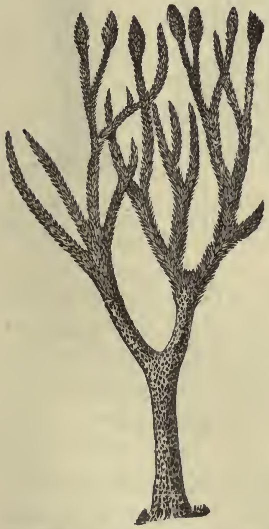

FIG. 235.—Restoration of a Lepidodendron. (By Dawson.)

There can be no doubt that the Lepidodendron was a lycopod, or club-moss; but its internal structure, as well as its great size (club-mosses are now but a few inches, or, at most, a few feet high), ally it strongly with conifers. We may regard it, therefore, as a lycopod, with characters connecting it with conifers.

2. **Sigillarids.**—The family name is taken from the type genus, *Sigillaria.* It includes Sigillaria and Sigillarialike plants. The name Sigillaria is taken from the

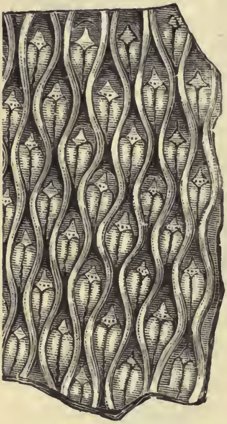

Fig. 236.—Lepidodendron modulatum. (After Lesquereux.)

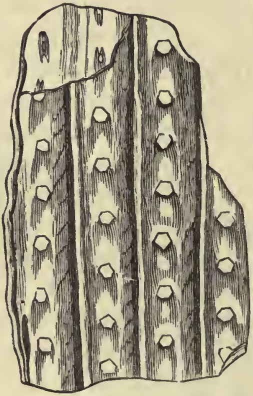

Fig. 237.—Sigillarids: Sigillaria reticulata. (After Lesquereux.)

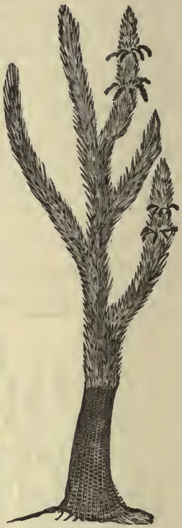

Fig. 238.—Restoration of Sigillaria. (By Dawson.)

seallike markings (*sigilla,* a seal) left on the trunk by the falling leaves (Fig. 237). They were the largest of all the coal-trees. Root, stem, branches, and leaves have been found. From these it is possible to reconstruct the general appearance of the tree. Imagine, then, a tree four or five feet in diameter at the base, with widely spreading roots; the trunk regularly fluted like a Corinthian column, and ornamented with vertical rows of seallike impressions (leaf-scars), and towering to the height of one hundred to one hundred and fifty feet; the top branchless, or else with only a few large branches clothed with grasslike or yuccalike leaves. The fruit is not known with certainty. The general appearance is given in Fig. 238.

3. **Calamites.**—These are so named from their jointed, reed-like appearance (*calamus*, a reed). They are usually found in the form of flattened, jointed, and striated stems. They may be described as follows: Imagine a straight, hollow, jointed, tapering stem, one to two feet in diameter, and twenty, thirty, or forty feet high, terminating in a compact, cone-like fruit (Fig. 240), the joints striated, but the grooves interrupted at the joints by whorls of scale-like leaves, or else whorls of jointed, thread-like branches (Fig. 239) about the joints. From the basal joints come out thread-like roots. Fig. 239 is a restoration of its appearance.

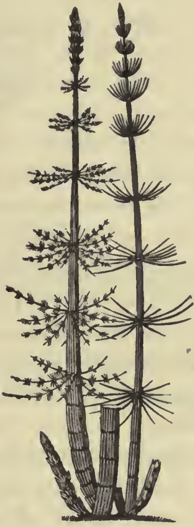

Fig. 239.—Restoration of a Calamite. (After Dawson.)

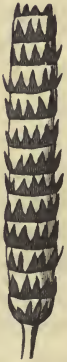

Fig. 240.—Fruit of Calamite. (After Heer.)

Now, all that we have said applies, word for word, to equisetæ, or horse-tails, except the great size. But equisetæ of the present day are small, rushlike or reedlike plants. Moreover, the internal structure of Calamites shows a close relation with gymnosperms, probably conifers.

Conclusion.—The general conclusion, then, is that all the plants of the Coal, but especially the Lepidodendrids, the Sigillarids, and the Calamites, were remarkable generalized types, connecting classes and orders now widely separated from each other—viz., the higher or vascular cryptogams with the lowest or gymnospermous phenogams. The two branches of the tree of life, cryptogam and phenogam, so widely separated *now,* when traced downward, approach and almost meet here in the Coal period.

Mode of Accumulation of Coal.

There has been much dispute on this subject, and it is still obscure. There are some things, however, which are reasonably certain. We shall give what is most certain, in the form of three propositions:

1. **Coal has been accumulated in the presence of water.**—This is indicated (*a*) by the nature of the plants, which are mostly swamp-plants; (*b*) by the interstratified sands and clays, which were, of course, deposited in water; but, more than all (*c*) by the preservation of the vegetable matter, which would have entirely disintegrated and passed off, as CO_2 and H_2O, unless completely water-soaked.

2. **Coal has been formed by accumulation of vegetable matter "in place"**—i. e., where the plants grew—by annual decay of generation after generation, as we see now in peat-bogs and peat-swamps; and *not by accumulation by driftage,* as we see in *rafts.* The evidence of this is complete. We shall only mention one fact, which is demonstrative: The *under-clay* of every coal is *full of stumps and roots* in position as they grew. Every under-clay is an old fossil forest-ground, or rather swamp-ground.

Imagine, then, an old coal-swamp, with its clay bottom full of dead stumps and roots, with its accumulation many feet deep of pure peat, with its surface covered with late-fallen leaves, broken branches, and prostrate trunks, and the still growing vegetation shading all. Now, imagine this overwhelmed and buried by sediments, subjected to powerful pressure and slow change, and we have all the phenomena of a coal-seam, with its under-clay full of roots and its roof-shale full of impressions of leaves and flattened branches, etc.

3. **Coal has been accumulated at the mouths of rivers,** and therefore subject to overflows and deposits of mud by the river, and to occasional incursions by the sea. This is proved by the alternation of river-sand and clay with marine deposits of limestone.

It may be difficult to put these three propositions together and form a clear picture of the precise manner of accumulation, and therefore there is still a large field for the play of fancy.

Estimate of Length of the Coal Period.

If the sands and clays of a coal-field have been accumulated by river-deposit, then we have a means of making a rough approximate estimate of the time embraced by the Coal period. It is true, agencies may have acted then at a different rate from now, but our estimate will be liberal.

For this purpose we take the Nova Scotia coal-field, because the evidence of river-deposit is very strong in every part. It has been estimated that there were not less than 54,000 cubic miles of river sediment in the original field. Now, the Mississippi River at present accumulates one twentieth cubic mile per annum, and would therefore take twenty years to accumulate one cubic mile, and 1,080,000 years to accumulate 54,000 cubic miles. But, as already said (page 298), the Coal period is but a small fraction, certainly not more than one twentieth to one thirtieth, of the recorded history of the earth. Therefore, this recorded history can not be less than twenty to thirty millions of years. It is probably much more. We only give this estimate in order to accustom the mind to the great periods of time with which geology deals.

Physical Geography and Climate of the Coal Period.

Physical Geography.—The Paleozoic era was a time of gradual growth of the continent from the Archæan nucleus by successive additions, first of the Silurian, then of the Devonian, and now of the Carboniferous area. During Carboniferous times the form of the American Continent probably did not differ greatly from that represented on page 349 (Fig. 303) as the Cretaceous continent, except that the areas of coal-measures were not then *permanent* land, but were in an uncertain state, sometimes swamp-land, sometimes covered with river-sediment, sometimes covered by the sea. Although the continent had greatly grown, still we must imagine it as small and low compared with its present state. The same is probably true of other continents.

Climate.—The climate was probably *warm,* very *moist,* very *uniform,* and the air *loaded with* CO_2. The greater warmth and uniformity are shown by the fact that the plants are those of a tropical climate. Tree-ferns, arborescent lycopods, etc., grew then with ultra-tropical luxuriance, not only in now temperate regions, but in Melville Island and Grinnell Land, 78°–80° north latitude. The prevalence of the great coal-swamps and the character of the plants are sufficient evidence of *greater humidity.* Finally, when we remember that the whole of the coal in the world represents so much carbon taken from the atmosphere, as CO_2 with return of the oxygen, we shall be convinced that the quantity of CO_2 in the air was greater and of oxygen less than now.

It is probable, therefore, that in early geological times there were more moisture and CO_2 and less oxygen than now. This would make a paradise for plants, especially the lower orders, but would be unsuitable for air-breathing animals. There has been throughout all geological times a gradual purification of the air of its superabundant moisture by increase of the size and height of continents, and of its superabundant CO_2 by its withdrawal in many ways, but during the Coal period especially by the growth of plants and the preservation of the carbon as coal. In this process not only was the CO_2 removed, but oxygen restored, and thus was the air prepared for the use of air-breathing, hot-blooded animals, such as birds and mammals, which were accordingly introduced soon afterward.

Petroleum and Bitumen.

We take up these here, not because they are peculiar to the coal-measures, for such is not the fact, but because they seem to have been formed from organic matter by a process similar to that of coal, and also because some think they are actually formed from coal by distillation. This, however, is not probable.

If bituminous coal, or any organic matter, be heated red-hot, *out of contact with air,* the volatile matters are driven off, broken up, and recombined, and may be collected in a great variety of forms of hydrocarbons—some solid, as *coal-pitch;* some tarry, as *coal-tar;* some liquid, as *coal-oil;* some volatile, as *coal-naphtha;* and some gaseous, as *coal-gas.* Now, a somewhat similar series of hydrocarbons is found in the earth and issuing on its surface: some solid, as *asphalt, Albertite, Grahamite,* etc.; some tarry, as *bitumen;* some liquid, as *petroleum;* some volatile, as *rock-naphtha;* some gaseous, as the *gas of burning-springs.* It is almost certain also that these are of organic origin.

Mode of Occurrence.—Petroleum occurs in the strata much as water does, and the two are often associated. Like water, and with water, it is found in porous and fissured strata, such as sandstones and limestones, when these are covered with a stratum of impermeable shale.

Like water, and with water, it often oozes on the surface as hillside springs. With water, it collects in fissures and cavities of all kinds, from which, through artesian wells, it issues, in some cases, in great quantities as fountains.

But, unlike water, there is no great, continuous, perennial supply; and also, unlike water, the force by which it spouts is not by hydrostatic pressure alone, but hydrostatic pressure transmitted through the elastic force of compressed gas always associated with the oil. As gas, oil, and water are nearly always found together, these arrange themselves in the order of their relative specific gravities; and therefore in a flowing well the water usually appears only after the gas and oil are exhausted. The flow of oil wells is not perennial like water, because the oil is not continually re-supplied. The accumulation of ages is now being exhausted with a rapidity proportioned to the abundance of the flow. What is true of oil is much more true of gas. A gas well is necessarily short-lived.

Age of Petroleum-bearing Strata.—Petroleum has been found in strata of nearly all ages, but under the two *conditions* of local abundance of the organic matter from which this substance is formed, and the absence of metamorphism, which always changes it into asphalt. At one time it was supposed to be characteristic of newer rocks, having been found in foreign localities, mostly in Tertiary strata. But in the Eastern United States it is confined to the Paleozoic rocks, while in California it is again found only in the Tertiary.

The great petroleum area of the Eastern United States is the Paleozoic basin. In this basin it is found on several horizons, but always *below* the coal-measures. The most celebrated, viz., the Pennsylvania horizon, is in the Upper Devonian. The Canada horizon is in the lowest Devonian. In West Virginia it is in the sub-Carboniferous. In Ohio it is in the Devonian and in the Silurian, especially the latter. In California it is in the Miocene Tertiary of the Coast Range.

Origin of Petroleum.—It is probable that petroleum was formed by a change of organic matter, somewhat similar to that which makes coal, but from a different kind of organic matter, and under different conditions. Land-plants, in the presence of fresh water, form coal; while marine plants, and sometimes lower animals, in the presence of salt water, form petroleum, bitumen, etc. It has been observed that petroleum is often found in connection with salt.

Origin of Varieties.—But, however formed in the first instance, there is no doubt that the different varieties or physical conditions are formed from each other by the passing away of gaseous hydrocarbon. In this manner light oil changes into heavy oil, and this into bitumen, and finally into asphalt. Thus there are two series derived from organic matter, the coal series and the petroleum series. By successive changes, coal passes from fat-coals to bituminous, then semi-bituminous, then anthracite, and finally graphite; petroleum from light oil to heavy oil, then bitumen, asphalt, jet, and possibly diamond. But the origin of diamond is uncertain.

Fauna of the Carboniferous Age.

As already stated, we shall take up the fauna of the sub-Carboniferous and Carboniferous together; only let it be remembered that the land and fresh-water animals are from the coal-measures, especially the vertebrates, and the marine animals are mostly from the sub-Carboniferous. We shall touch only the most prominent points.

We have nothing characteristic to add about *corals,* but only draw attention here to an exceedingly curious and characteristic form of coral-making Bryozoan, called from its perfect screw-like form, *Archimedes* (Fig. 241). This abundant and easily recognized form is wholly characteristic of the sub-Carboniferous. By studying the diagram (Fig. 243) the main facts regarding *Echinoderms* may be easily remembered. As before (page 279), the lower shaded part represents stemmed, and the upper unshaded, the free forms. The Cystids, it is seen, are confined to the Silurian, the Blastids commence in the Silurian, continue through the Devonian and Carboniferous, and perish; while the Crinids continue until now. The Asteroids commence in the Lower Silurian, the Echinoids in the Carboniferous, and both continue until now—the species, of course, changing. As Blastids are very abundant in the sub-Carboniferous, we give a figure (Fig. 242).

Concerning *Mollusca,* we touch two points: 1. Fresh-water and land shells, which were introduced in the Devonian, are more abundant (Figs. 244, 245). 2. The Goniatites, first introduced in the Devonian, are also more numerous here (Fig. 246).

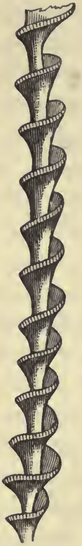

FIG. 241.—Archimedes laxa. (After Hall.)

Concerning *Crustacea,* also two points: 1. While Trilobites continue under new forms, ready to perish at the end of this period, *Lmiuloids,* or horseshoe crabs, a higher type, are here introduced (Fig. 247). The transition from Trilobites to Limuloids may be quite perfectly traced. 2. True typical crustaceans of the long-tailed kind (Macrourans), such as shrimps and the like, were first introduced here (Fig. 248).

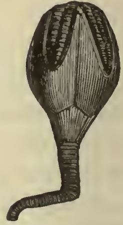

FIG. 242.—Blastid: Pentremites pyriformis. (After Hall.)

Insects, which first appeared in the Devonian in connection with land vegetation, as might be expected, are much more abundant and in greater variety in

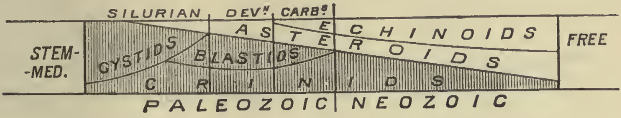

FIG. 243.

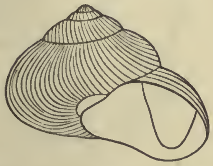

FIG. 244.—Dawsonella Meekii. (After Bradley.)

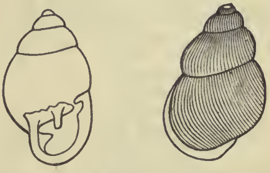

FIG. 245.—Anthracopupa Ohioensis. (After Whitfield.)

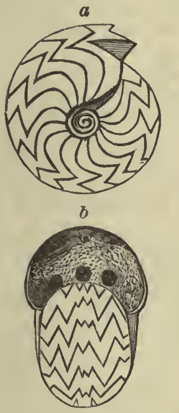

FIG. 246. — Carboniferous goniatites: Goniatites crenistria (European); *a*, side-view; *b*, end-view.

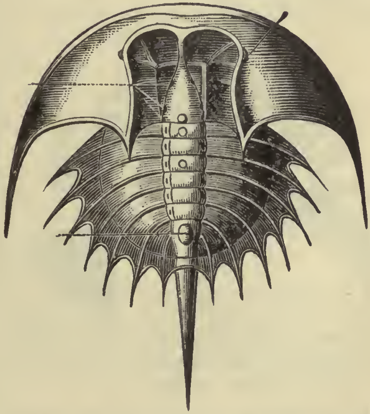

FIG. 247.—Carboniferous crustacean: Euproöps Danæ. (After Meek and Worthen.)

the coal-measures. There are spiders, scorpions, centipeds, cockroaches, dragon-flies, and beetles (Figs. 249, 250). It is well to observe that the highest orders of insects, flower-loving, honey-loving, and social, such as flies, butterflies, bees, and ants (*Dipters, Lepidopters,* and *Hymenopters*), are not yet found, because there are not yet any *flowering* plants.

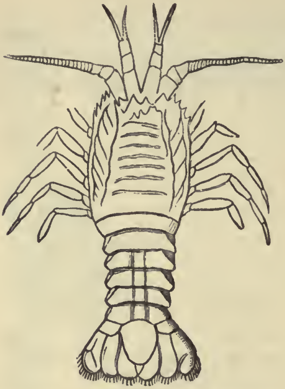

FIG. 248.—Carboniferous crustacean: Anthrapalæmon gracilis. (After Meek and Worthen.)

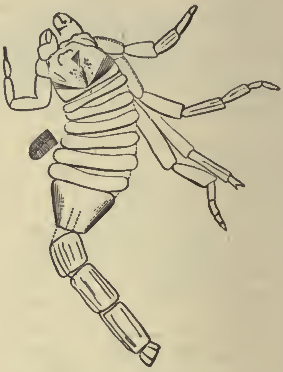

FIG. 249.—Carboniferous insect: Blatta maderæ, wing-cases. (After Lesquereux.)

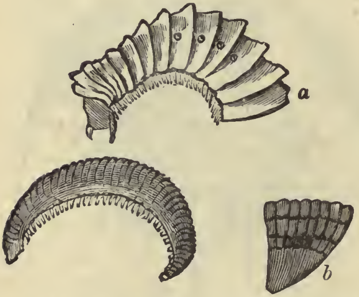

FIG. 250.—Carboniferous insects: Zylobius sigillariæ. (After Dawson.) *a*, anterior; *b*, posterior portion, enlarged.

Fishes.—We have little to add here to what has already been said under the Devonian. The same kinds of fishes—viz., Ganoids and Placoids—still prevail. Of the Ganoids, however, the Placoderms passed away with the Devonian, but the Lepidoganoids continue, and some of them become still more reptilian. We note also an advance in the Placoids, in that an intermediate form (the *Hybodonts*) between the Cestracionts and true sharks (*Squalodonts*) here appears.

Amphibians.—The introduction of amphibians must be regarded as a great step in the progress of life; for they are the first true *land* vertebrates and *air-breathing* vertebrates. Yet we must remember, on the one hand, that amphibians, as their name implies, all of them at some period of their life, some of them permanently, breathe both air and water—both by gills and by lungs; and on the other hand we must remember that Ganoid fishes also supplement their gill-breathing by lung-breathing. The amphibians are intermediate between fishes and true reptiles. They are represented now by frogs, toads, newts, etc.

Now, in the Carboniferous, and long afterward, amphibians were very different from any of those mentioned as still living. They belonged to a peculiar order now long extinct, called *Labyrinthodonts*, from the labyrinthine structure of their teeth (Fig. 252). All the *living* amphibians are small creatures; these were often of huge size. All the living kinds have soft, moist skin; these were partly covered with large, ganoidal plates. The early Ganoids, too, had the same labyrinthine structure of the teeth, though less marked (Fig. 251). In fact, the transition from the reptilian Ganoids to the ganoidlike amphibians of the coal-measures is so gradual that it is difficult in some cases to say whether some of these are amphibian reptile or ganoid fish (Fig. 253).

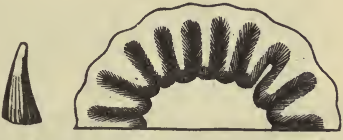

FIG. 251.—Structure of a ganoid tooth. (After Agassiz.)

Amphibians seem to have been very abundant in the coal-measures—some snakelike forms, with very small or no feet, some lizardlike forms, some fishlike forms, and some huge crocodilian forms, but not with crocodilian affinities. These huge forms were, however, more common later, i. e., in the Triassic. We will describe only two examples :

The Archegosaurus (*primeval saurian*) (Fig. 253) was an animal two to three feet long, with head and body much like a ganoid fish, and covered with ganoid plates and scales. It had probably permanent gills as well as lungs, and its legs were little more than legged fins, such as are found in some ganoids, and wholly unadapted for locomotion on land. It was a remarkable connecting link between ganoid fish and labyrinthodont amphibian.

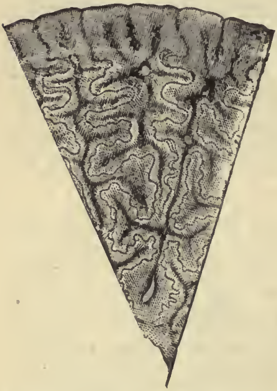
FIG. 252.—Section of portion of a tooth of a labyrinthodont.

The Dendrerpeton (*tree-reptile*) was so called because first discovered (by Dawson) in the hollow stump of a sigillaria tree. It was of lizard-like form, and about two feet long It is a curious fact that these hollow stumps of sigillaria filled with sandstone (Fig. 254) are very rich in fossils, e. g., skeletons of amphibians, remains of insects, and shells of land mollusca. The sigillaria tree was very soft and spongy, but was covered with a hard bark. We may easily picture to ourselves the conditions under

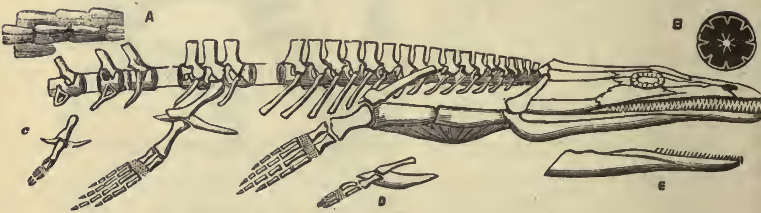

FIG. 253.—Archegosaurus : A, plates ; B, section of tooth.

which these remains were entombed. Imagine, then, a large sigillaria tree on the borders of a coal-swamp, rotted down to a hollow stump. A flood then carried thither floating insects, shells, and carcasses of amphibians, which lodged in the hollow stump, and were covered up with sand. The hollow stump changed to coal, the sand to sandstone, and the animal remains to fossils.

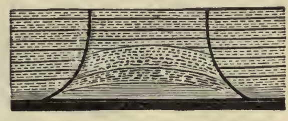
Fig. 254.—Section of hollow sigillaria stump, filled with sandstone. (After Dawson.)

The very earliest amphibian known is recognized by its tracks (Fig. 255). These are found in the sub-Carboniferous of Pennsylvania, in a sandstone marked with ripple-marks. The animal has been called *Sauropus primævus* (primeval reptile-foot). It was evidently a large Labyrinthodont. Not only tracks and ripple-marks, but also rain-prints (Fig. 256) and sun-cracks, are common in the coal-measures.

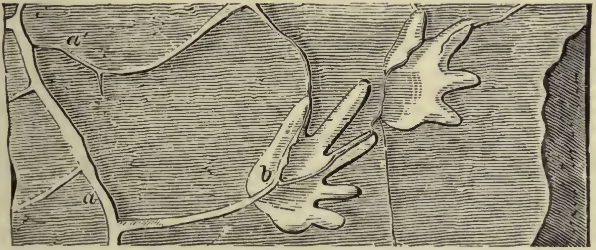

Fig. 255.— Slab of sandstone with sun-cracks *a*, and reptilian footprints *b*, from coal-measures of Pennsylvania ; × $\frac{1}{6}$.

Some General Observations on the Whole Paleozoic.— Before leaving this long and diversified era, we must look back and make some general observations.

Progressive Change.—During the whole time we may observe a progressive change going on: 1. There was, as we have seen, a steady *growth* of the continent from the Archæan nucleus. 2. There was also a progressive change in the constitution of the atmosphere, especially by removal of excess of water and CO_2, fitting it for the introduction of higher animals. 3. In connection with these physical changes, there were also progressive changes in life-forms.*

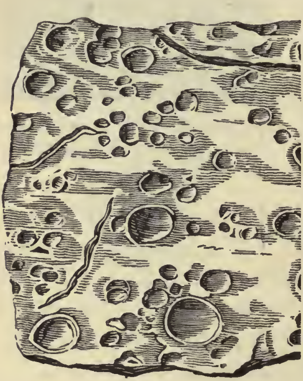

FIG. 256.—Fossil rain-prints of the Coal period.

Appalachian Revolution.—Thus we see a slow, steady, progressive change *during* the era. But now, at *the end*, there occurred one of those great and rapid changes in physical geography and climate which mark the end of the eras, and a corresponding sweeping change in the forms of life. The Appalachian chain was formed at this time, and is its monument, and therefore, by American geologists, it is fitly called the *Appalachian Revolution*. The place of the Appalachian chain during the Silurian and Devonian eras was the marginal sea-bottom of the great interior Paleozoic Sea, receiving sediments until 30,000 feet were accumulated. During the Carboniferous it was sometimes an inland sea-bottom, sometimes a coal-marsh, and sometimes, perhaps, a lake, but always receiving sediment until 10,000 more feet were accumulated. Now, at last, it yielded to the ever-increasing lateral pressure, and was folded and crumbled with all its coal-beds, and swelled up into a great mountain-range. It has since been sculptured by erosion into its present forms.

We have said that the change of life-forms produced by this revolution was sweeping. When quiet and prosperous times again commenced, in the Mesozoic, we find an entirely different condition of things. It is almost like a *new world.* We must not imagine, however, that the change was absolutely *sudden.* The steps of change here were only *more rapid,* and the general *unconformity* and *loss of record* which occur here make it *seem* sudden.

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* For a fuller account of this important point, the teacher is referred to the larger work.

Transition to the Mesozoic Era.—Permian Period.

We have seen (page 267) that the Paleozoic *commenced* after a great revolution. Now, the Paleozoic was *closed* also by a similar revolution. We have called this latter the Appalachian Revolution, because this range was made at that time ; but it was a time of widespread oscillations, and, therefore, of great changes in physical geography and climate, marked by universal unconformity and by sweeping changes in life-forms. Now, as already seen on page 193, unconformity always means *lost record* at that place. Of the lost record between the Archæan and Paleozoic nothing has been certainly found, but of that between the Paleozoic and Mesozoic, certain leaves have been recovered. These are brought together and called the *Permian.* Some have allied the Permian with the Mesozoic under the name of Dyas. Others have allied it with the Paleozoic. The truth is, it ought to be regarded as a period of transition or of revolution between the two.

Life System.—As might be expected the organisms of the Permian are mainly transitional. Paleozoic forms are passing away and Mesozoic forms are coming in. The very first reptiles are introduced here, but they had not yet attained supremacy.

CHAPTER IV.

MESOZOIC ERA.—AGE OF REPTILES.

The Paleozoic era was very long and diversified. It consisted of three ages—the age of Invertebrates, the age of Fishes, and the age of Acrogens and Amphibians. The Mesozoic era, on the contrary, consists of but one age—the *age of Reptiles.* Never, in the history of the earth, were reptiles so abundant, of such size and variety, or so highly organized, as then.

Characteristics of the Age.—The characteristics of this age are the *culmination* of the class of *reptiles,* and the class of *cephalopod* mollusks among animals, and of *cycads* among plants ; and the *first introduction* of *mammals* and *birds,* and, in the last part, of *Teleost fishes* and *Dicotyledonous trees.* The most striking characteristic is the culmination of reptiles, and this, therefore, gives it its name.

Subdivisions.—The Mesozoic era and Reptilian age is divided into three periods—viz. : 1. *Triassic,* on account of its distinct threefold division in Germany, where first well studied. 2. *Jurassic,* on account of its splendid development in the folded structure of the Jura Mountains. 3. *Cretaceous,* on account of the chalk of England and France being one of its members.

Mesozoic rocks.
- 3. Cretaceous.
- 2. Jurassic.
- 1. Triassic.

These three are very distinct periods in Europe, but in America the Trias and Juras are closely connected though very distinct from the Cretaceous; so that, studied in America alone, it would be most natural to divide the whole age into two periods: 1. *Jura-Trias;* and, 2. *Cretaceous.*

Again, the Jura-Trias is much poorer in fossils in this country than in Europe; so that, if we treated of American strata alone, we should give but a very imperfect picture of the times. Therefore, our plan will be to give a brief sketch of the Trias, and then of the Juras, taking illustrations chiefly from foreign sources, and then a sketch of the Jura-Trias in America. The Cretaceous can be fully illustrated from American strata.

SECTION I.—TRIASSIC PERIOD.

As already stated, the lowest Mesozoic (Triassic) is always, or nearly always, unconformable with the Coal. The line of break may be between the Triassic and the Permian, but more commonly between the Permian and the Coal. But the fossils of the Triassic are always very different from those of the Permian. The break in the life system is always greatest here. We will neglect the subdivisions, and take up all together.

Life System.—Although the revolution which closed the Paleozoic is passed, and comparative quiet again restored, yet it took some time for the old fullness of life to recover itself. Mesozoic life, therefore, is comparatively poor in the Triassic compared with the Jurassic and Cretaceous. We will, therefore, touch very briefly on Triassic life.

The Change.—The most striking fact is the sweeping change in life-forms. All the old style corals are replaced by new style; all the armless crinoids (Blastids and Cystids), the square-shouldered brachiopods, the orthoceratites and trilobites, the lepidodendrids, sigillarids, and calamites—in a word, all that we found most characteristic of the Paleozoic, are gone. They are replaced by other and very different forms.

Plants.—As the grand characteristic of the Coal period was the predominance of the vascular Cryptogams, so that of this period is the predominance of the next higher group of plants, viz., *Gymnosperms,* i. e., Conifers and Cycads, especially *Cycads* (see diagram on page 259). Ferns and Equisetæ, however, still abounded, though of different genera from those of the Coal. But as the peculiar flora of the Mesozoic did not culminate until the Jurassic, we shall put off illustrations until that time.

Animals.—Although Cystids and Blastids disappear with the Paleozoic, the Crinids are still represented by many beautiful new forms, with plumose arms, which, when expanded, must have presented a truly flower-like appearance, and their fossilized remains are therefore often called *stone-lilies.* One of these is shown in Fig. 257, and on page 331 we give a similar form in expanded condition.

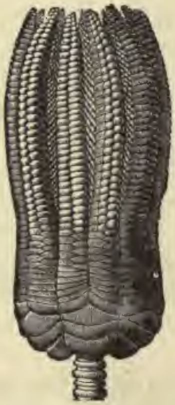

FIG. 257.—Encrinus liliformis

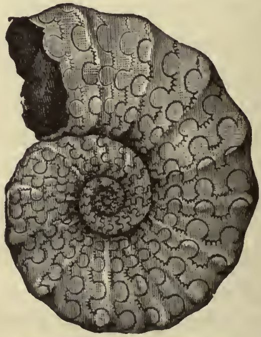

FIG. 258.—Ceratites nodosus.

The Goniatites have passed away. The Ammonite family is here represented by *Ceratites*. They are easily recognized, and entirely *characteristic of the Triassic*. The complexity of the suture is increased, as shown in Fig. 258.

Fig. 259.—Teeth of Triassic fishes; Hybodus apicalis. (After Agassiz.)

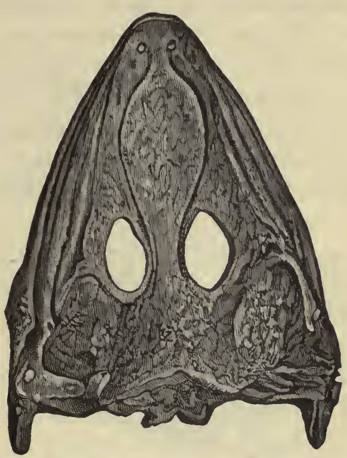

Fig. 260.—Mastodonsaurus Jaegeri; × $\frac{1}{16}$.

Among *fishes* we find still only Ganoids and Placoids, but the Ganoids are assuming more and more the form of ordinary fishes (Teleosts), and the teeth of the Placoids are becoming more shark-like (Fig. 259).

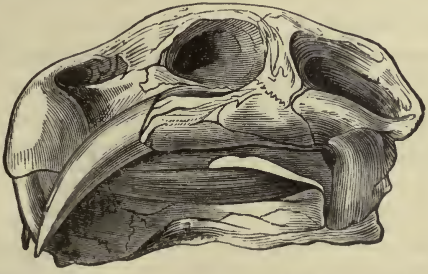

Fig. 261.—Triassic reptiles (after Owen)—anomodonts and therodonts; Dicynodon lacerticeps.

Amphibians.—Labyrinthodonts, introduced in the Coal, continue and culminate here (Fig. 260), and soon become extinct.

Reptiles.—Reptiles were introduced in the Permian but did not become dominant until the Mesozoic. Certain forms, of which we shall speak hereafter, commence here, but culminate in the Jurassic. But there are also some curious transitional forms entirely characteristic of this period. The Anomodonts (lawless-toothed) were beaked like a turtle, and either toothless or else with long tusks only (Fig. 261), but crocodilian in form. The *Therodonts* (beast-toothed) were so called because their teeth were in three groups, corresponding to *incisors, canines,* and *molars* of mammals (Fig. 262). Both of these curious families had many characters allying them with the lowest mammals, i. e., *Monotremes* (Ornithorhynchus, Echidna, etc.), now found only in Australia. They have been fitly called, by Cope, *Theromorpha* (beast-like). These beast-like reptiles seem to have been introduced first in the Permian.

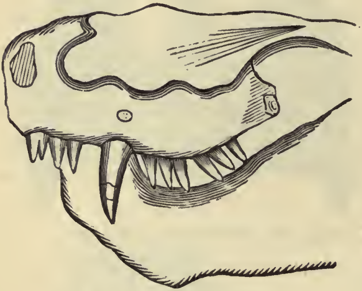

Fig. 262.—Lycosaurus.

Mammals.—If beast-like reptiles are found here, we might naturally expect also the lower forms of beasts themselves. In the uppermost Triassic, both of Europe and America, remains of small marsupial mammals have indeed been found; but as only a *few* have been found, and these in the uppermost Triassic, almost passing into the Jurassic, and as similar remains are far more abundant in the Jurassic, we shall put off their description until that time.

No *birds* have been found. It may seem strange that mammals should have been introduced before birds ; but we find the explanation of this in the fact that birds are a *sub-branch* of the reptilian branch of the vertebrate stem.

SECTION II.—JURASSIC PERIOD.

Name.—These strata and the period they represent are called Jurassic, because of their splendid development in the folded structure of the Jura Mountains (Fig. 145, page 241) and their richness in fossils there.

Rock-System.—In England the Jurassic has been subdivided into the *Lias*, the *Oölite*, and the *Wealden ;* but we shall neglect these, and speak only of the whole together.

Coal.—One point worthy of note here is the occurrence of *coal*. The Jurassic coal-fields are far smaller than those of the Carboniferous, but the mode of occurrence of the coal is much the same.

Examples of such coal are the Yorkshire and Brora coal of Great Britain, and some of the coals of India and China ; also the coals of eastern Virginia and North Carolina. Of these last we shall speak again. Many Jurassic coals are of excellent quality, though the average is inferior to the coal of the Carboniferous.

Plants.—The characteristic families of the Jurassic are Ferns, Conifers, and Cycads. Conifers and Cycads, especially *Cycads*, culminated in this period ; they are found in extreme abundance in connection with the Jurassic coal in the form of leaves, trunks, and roots. Some Jurassic plants and their living allies are shown in Figs. 263–266.

Animals.

The culmination of the characteristic animals of the Mesozoic, especially reptiles, occurred in this middle period. We shall touch very briefly all except the most important characteristic kinds.

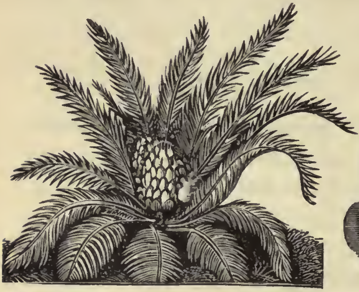

Fig. 263.—Zamia spiralis, a living cycad of Australia.

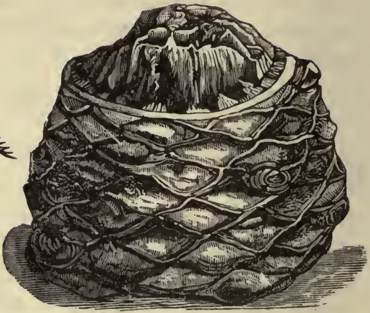

Fig. 264.—Stem of cycadeoidea megalophylla.

Crinoids, beautiful, plumose-armed, and lilylike, are abundant (Fig. 267) ; but so, also, are the free asteroids and echinoids (Fig. 268). The two kinds, stemmed and free, are evenly balanced.

Bivalves are, of course, abundant and of characteristic forms, in this as in all geological times ; but we can only draw special attention to the oyster family (including *Ostrea, Gryphea, Trigonia,* etc.), which were first introduced here (Figs. 269–271).

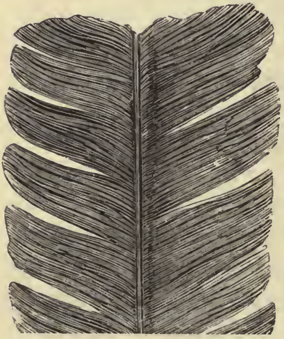

Fig. 265.—Jurassic plants : Pterophyllum comptum (a cycad).

Ammonites. — The Ammonite family were introduced first in the Devonian as Goniatites. These were replaced in the Triassic by Ceratites. The Ammonites proper, the highest type of the family, were introduced in the early Mesozoic, culminated here in the Jurassic, continued through the Cretaceous, and died out at its end. It is, therefore, characteristic of the Mesozoic. In the Jurassic they were of extreme abundance, and of all

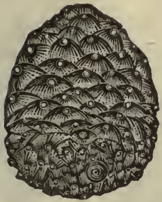

FIG. 266.—Jurassic plants—Conifers : Cone of a pine.

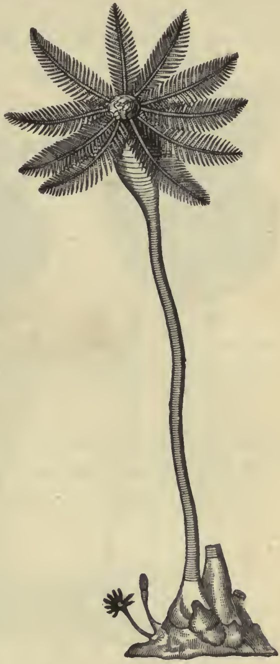

FIG. 267.—Apiocrinites restored. (After Buckland.)

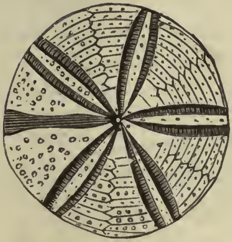

FIG. 268.—Clypeus Plotii.

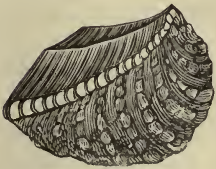

FIG. 269.

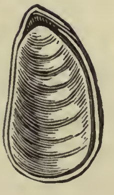

FIG. 270.

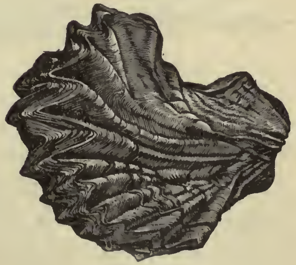

FIG. 271.

FIGS. 269-271.—Jurassic lamellibranchs of England : 269. Trigonia clavellata. 270. Ostrea Sowerbyi. 271. Ostrea Marshii.

sizes, from half an inch to three feet in diameter. We give some figures of the most characteristic forms (Figs. 272–274).

It is interesting to trace the gradual changes in the form of the suture in shelled cephalopods. In the Silurian Orthoceratites the sutures were even; in the Devonian and Carboniferous Goniatites they were angled; in the Triassic Ceratites they were scalloped; finally, here in the Ammonites they were *frilled* in the most complex patterns.

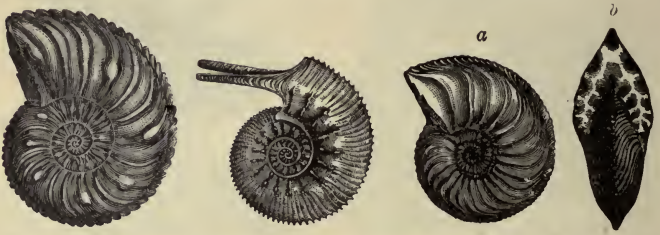

Fig. 272. Fig. 273. Fig. 274.

Figs. 272-274.—Jurassic cephalopods—Ammonites: 272. Ammonites margaritanus. 273. Ammonites Jason: side-view. 274. Ammonites cordatus: *a*, side-view; *b*, showing suture.

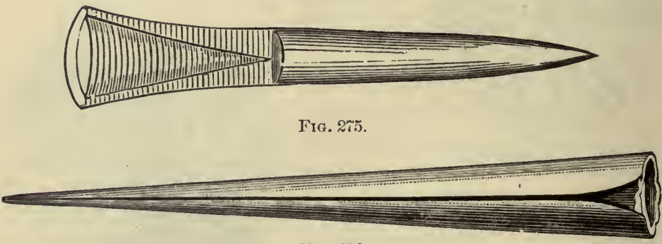

Fig. 275.

Fig. 276.

Figs. 275, 276.—275. Belemnites Owenii. 276. Belemnites unicanaliculatus.

Belemnites.—Now, for the first time, we find the highest order of cephalopods, viz., the naked ones, allied to the squids, cuttle-fishes, etc. This order is represented in Jurassic times by a peculiar form, called Belemnites, from the curious, *dartlike* bone (Figs. 275, 276), which is often the only part found. Sometimes the soft parts have been found; the ink-bag (Fig. 277) has been found so perfect that good ink has been made of it, and the animal has even been drawn with its own fossil ink. From the various parts found it is possible to restore the animal with some confidence. In Fig. 278 we give such a restoration, and in Fig. 279 a living squid for comparison.

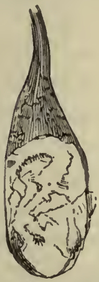

Fig. 277.

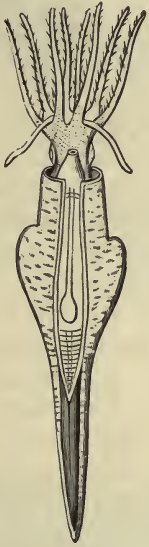

Fig. 278.

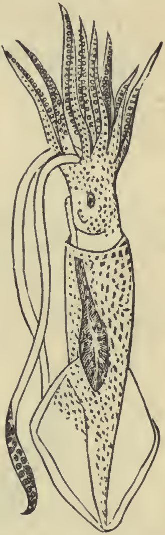

Fig. 279.

Figs. 277-279.—277. Fossil ink-bags of Belemnites. 278. Belemnite restored. 279. A living squid.

Crustaceans and Insects.—There is a steady development, during the Mesozoic, of crustaceans, toward the highest form, viz., the *crabs*. This, however, was *fairly* attained only in the Cretaceous, though a spider-crab has been found in the Jurassic.

Insects also are far more numerous and diversified (Figs. 280, 281) than heretofore, although even yet the highest forms, such as ants, bees, and butterflies, are not found.

There is little of importance to be noted in regard to Fishes. We therefore pass on to *Reptiles*.

Reptiles.—These are the rulers of the age, and culminate in this period. We shall therefore dwell a little more fully on them. During the Jurassic there was a truly extraordinary development of this class, in number, size, variety, and degree of organization. They were rulers in every department of Nature: rulers in the sea, in place of whales and sharks of to-day; rulers on the land, in place of beasts; and rulers in the air, in place of birds. We shall take them up under the three heads indicated, viz.: 1. *Marine Saurians* (Enaliosaurs). 2. *Land Saurians* (Dinosaurs). 3. *Winged Saurians* (Pterosaurs). The first were swimming, the second walking, the third flying, animals.

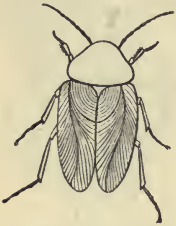
FIG. 280.—Jurassic insects: Blattina formosa. (After Heer.)

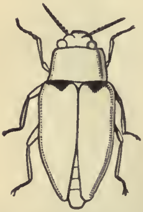
FIG. 281.—Glaphyroptera gracilis. (After Heer.)

1. **Marine Saurians.**—Among these we shall mention only the two most noted, viz., *Ichthyosaurus* and *Plesiosaurus*. The *Ichthyosaurus* (fish-reptile) (Fig. 282) was a huge monster, thirty to forty feet long, with thick body, short neck, enormous head, eyes twelve to fifteen inches in diameter, and jaws set with hundreds of conical teeth. The limbs were paddles, suitable for swimming, not for walking. The powerful tail was expanded vertically into a fin at its extremity, and the bodies of the vertebræ were biconcave like those of a fish. Perfect skeletons of this animal have been found; and even the impressions of its intestines, and the contents of its stomach, revealing the nature of its last meal, have been preserved.

The *Plesiosaurus* (lizardlike) (Fig. 283) was a slenderer animal, with a very long neck, small head, short tail, long and powerful paddles, and fishlike vertebræ.

2. **Dinosaurs,** or **Land Saurians.**—The hugest of

reptiles—in fact, the hugest animals which have ever walked the earth—were of this order. They were also the most highly organized of reptiles; for, if the marine saurians connected this class with fishes, the dinosaurs connected it with the higher class of birds. Some of the characters connecting them with birds are the following: 1. Many of them had long, powerful hind-legs, large hip-bones, and strong sacrum, and very short and small fore-legs. These characters show that they walked mainly on their hind-legs, in the manner of birds. 2. Many of them, like some birds, had only three toes on the hind-feet, so that they made tracks which were bird-like. 3. There were peculiarities about their ankle-joints which were still more bird-like.

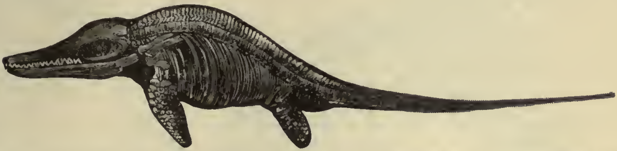

FIG. 282.—Jurassic reptiles—Ichthyosaurus and Plesiosaurus: Ichthyosaurus communis, × $\frac{1}{100}$.

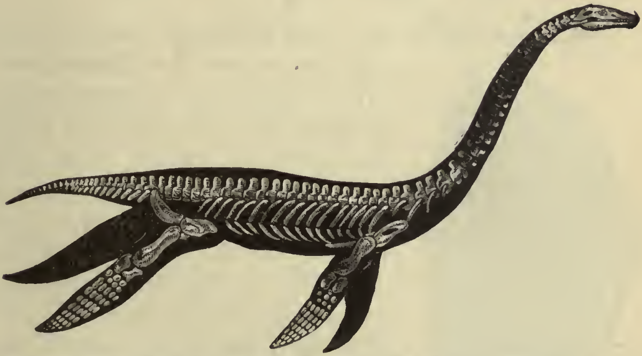

FIG. 283.—Jurassic reptiles—Ichthyosaurus and Plesiosaurus: Plesiosaurus dolichodeirus, restored, × $\frac{1}{80}$.

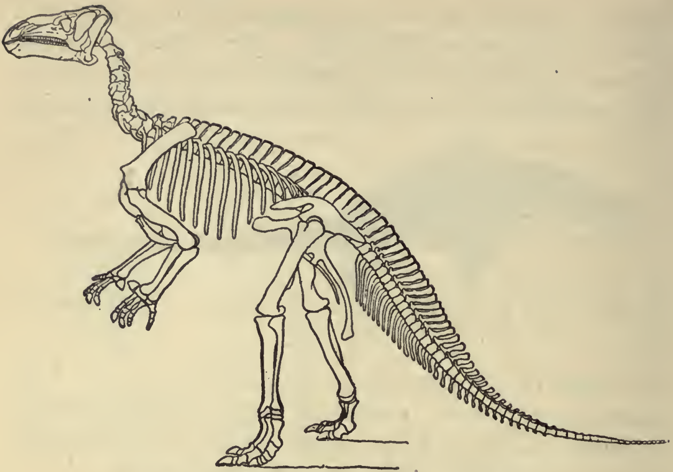

FIG. 284.—Iguanodon Bernissartensis. (After Marsh.)

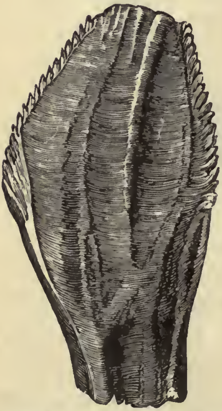

FIG. 285.—Tooth of an Iguanodon.

The most noted of this order found in Europe are the *Iguanodon* and the *Megalosaurus*. The iguanodon (Iguana-tooth), judging from the size of its bones, was probably several times more bulky than the elephant; and yet a perfect skeleton, recently found in Belgium (Fig. 284), shows that it walked on the hind-legs alone, supporting itself by its massive tail. The neck was long, flexible, and bird-like, and the jaws were beaked in front and set with herbivorous, iguanalike teeth (Fig. 285) behind. The *megalosaur* (great saurian) was not quite so large, but probably still more formidable, since it was carnivorous. A restoration of a smaller allied form is given in Fig. 286. This also walked mainly on two legs. Still much larger animals of this order have been found in the United States, as we shall see further on.

3. **Pterosaurs, or Winged Saurians.**—These are perhaps the most extraordinary of all known animals. They combined the stout body with keeled breastbone, the long, flexible neck and beaklike jaws of a bird, with the long arms and membranous flying-web of a bat and the essential characters of a reptile. In some cases they had a short, aborted tail, like a bird, but in others a long tail, with vertical expansion at the tip, which was used as a rudder in flying (Fig. 287). The pterosaurs varied in size from two or three feet to eighteen or twenty feet from tip to tip of the extended wings.

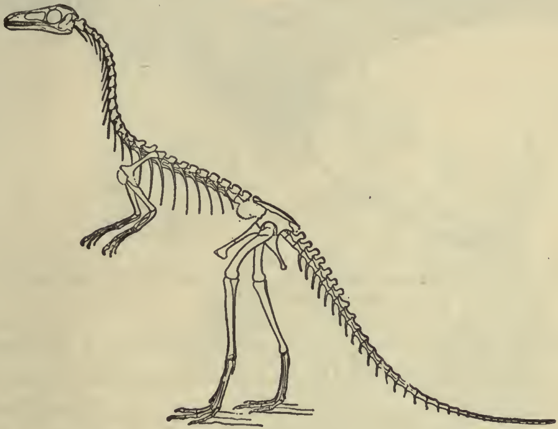

FIG. 286.—Compsognathus, × $\frac{1}{10}$. (Restored by Marsh.)

Birds.—We have seen that the reptiles of this time approached birds, but still more remarkably do the earliest birds approach reptiles. There is in Bavaria a peculiar limestone used the world over for lithographic drawings. This lithographic limestone is equally celebrated for its marvelous preservation of fossils. In 1862 the oldest known bird, the *Archæopteryx,* was found there with even the feathers, and the minute structure of the feathers of the wings and tail, preserved. An undoubted bird, yet how different from modern birds! Instead of the *short, aborted tail,* bearing feathers *radiating* almost from one point, as in all modern birds, it had a *long reptilian tail* with twenty-one joints, and the feathers given off in pairs *on the two sides of each joint.* Among many other reptilian characters are the possession of socketed *teeth,* and, instead of the hand being wholly consolidated to form the wing, as in modern birds, the three fingers remain free, and are armed with claws (Fig. 288).

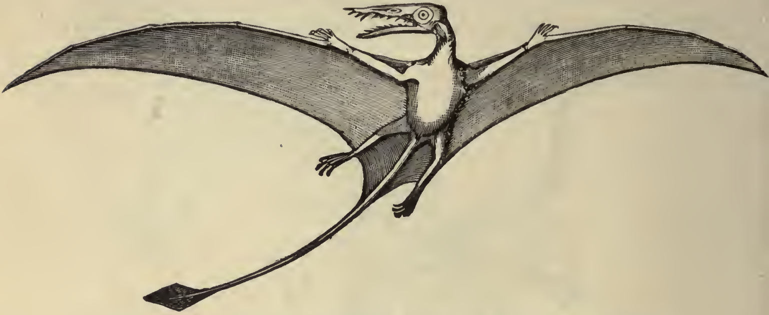

Fig. 287.—Restoration of Rhamphorhynchus phyllurus. (After Marsh.) One seventh natural size.

Another fine specimen of this wonderful bird was found, in 1873, in the same locality, and is now in the Berlin Museum. In the Jurassic dinosaurs and this Jurassic bird we have excellent examples of what we have called generalized or connecting types. These two branches—reptile and bird—which seem so widely distinct now, when traced backward in time, approach more and more, until we find almost their point of union.

Mammals.—We have already stated, on page 328, that a few small marsupial mammals are found in the uppermost Triassic, both of Europe and the United States. These we regarded as anticipations, and therefore put off their discussion. This anticipation is fully realized in the Jurassic. In England there have been found about eighteen species, and, in the United States, Marsh has found seventeen species; so that there are now known about thirty-five species of Jurassic and three species of Triassic mammals.

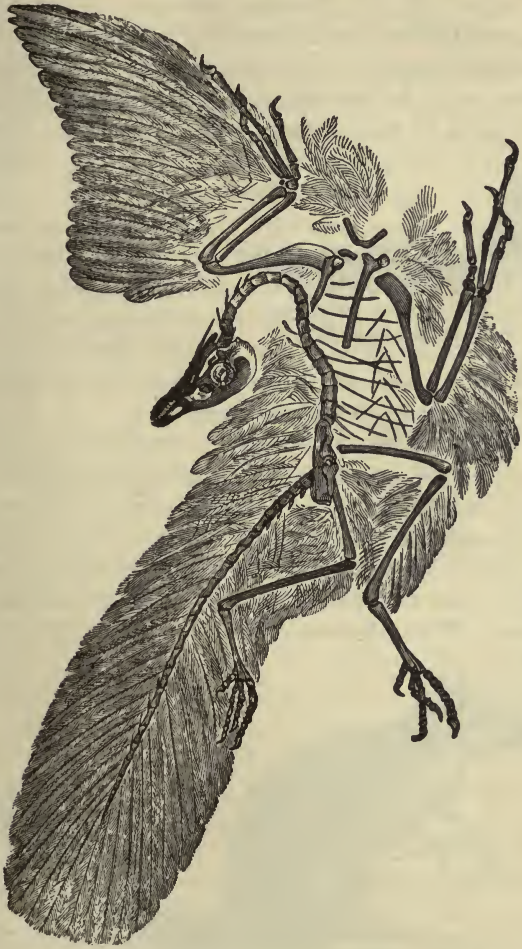

FIG. 288.—Archæopteryx macroura, restored. (After Owen.)

But, as the first birds were not true typical birds, but *reptilian birds*, so also the earliest mammals were not true typical mammals, but *reptilian mammals*, or *marsupials*. The marsupials live now almost wholly in Australia. They include the kangaroos, the opossums, the bandicoots, the wombats, etc. In Jurassic times they apparently inhabited all parts of the earth in great numbers. Now, the marsupials differ so greatly from ordinary mammals that they are put into a distinct subclass. One striking peculiarity about them is that their young are born in an exceedingly imperfect state, so that they are almost egg-bearing, *semi-oviparous*.

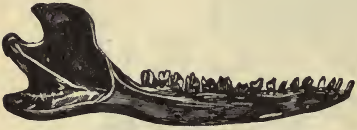

FIG. 289.—Jaw of a Jurassic mammal: Amphitharium Prevostii.

But neither were the Jurassic marsupials typical marsupials, but rather generalized types connecting with Insectivora, the lowest of the true mammals. They were all small animals, varying in size from that of a mole to that of a skunk. They were not able to contend for mastery with the great reptiles. The reign of mammals had not yet come. We give here (Figs. 289, 290) a jaw of a Ju-

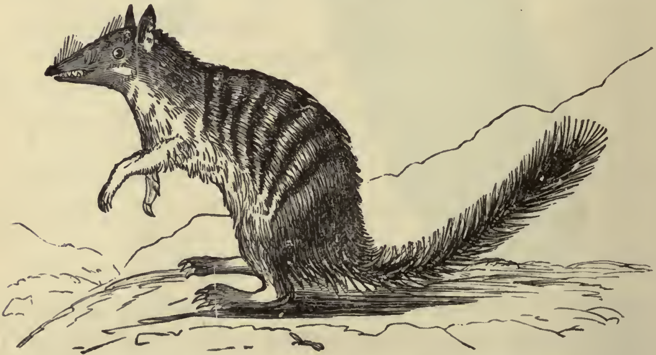

FIG. 290.—Myrmecobius fasciatus, banded ant-eater of Australia.

rassic marsupial, and also a living marsupial most nearly allied to them.

SECTION III.—JURA-TRIAS IN AMERICA.

Areas; Atlantic Border.—All along the eastern slope of the Appalachian chain, from Nova Scotia to South Carolina, in the Archæan region of the map on page 272, are found elongated patches of sandstones and shales which belong to this period. One of these is in Nova Scotia and Prince Edward Island; the next, going south, is the celebrated Connecticut River Valley sandstone; the next a long, narrow patch commencing in New York, passing through New Jersey, Pennsylvania, Maryland, and ending in northern Virginia; then two or three patches in eastern Virginia, about Richmond and Piedmont; and, lastly, some on the Deep River and the Dan River of North Carolina. They all lie in hollows unconformably on the Archæan gneiss, and therefore their age can not be known except by fossils; but these, though few, seem to indicate that they represent the whole *Jura-Trias*, although most writers speak of them as Triassic. In all these patches are found remarkable outbursts of igneous rocks, often columnar in structure, which by erosion have formed the so-called trap-ridges. Such are Mounts Tom and Holyoke, in the Connecticut Valley patch, and the Palisades of the Hudson River in the New Jersey patch.

Interior Region.—Red sandstones, poor in fossils, but probably referable to this period, are found in many places in the Plateau and Basin regions.

Pacific Slope.—On both sides of the Sierra, rocks of this age, in a metamorphic condition, form the auriferous slates of this region.

Life-System.

Life, no doubt, abounded, but the conditions were unfavorable for preservation. We can, therefore, take up only a few of these localities and give, briefly, the findings.

1. **Connecticut River Valley.**—This celebrated locality is classic ground, through the life-long labors of Dr. Hitchcock. The patch is one hundred and fifty miles long and ten to fifteen miles wide, extending from New Haven Bay, on Long Island Sound, through Connecticut and Massachusetts, and mostly on the two sides of the Connecticut River. As the strata dip regularly to the east, their thickness is easily estimated, and seems to be at least 5,000 to 10,000 feet. They consist of red sandstones and shales, and are in some places beautifully fissile. As might be expected from their redness,* they are very poor in fossils proper; but in certain parts an immense number of tracks of various animals have been found. There are tracks of (*a*) *insects* and *crustaceans;* (*b*) of *reptiles;* (*c*) possibly, but not probably, of *birds*.

(*a*) **Insects and Crustaceans.**—Of the insect and crustacean tracks little can be made out with certainty. We give an example (Fig. 291).

(*b*) **Reptiles.**—The reptilian tracks vary in *size*, from those of a lizard to those of the huge Otozoum, twenty-two inches long with a stride of four feet. In *character*, some are five-toed, some four-toed, some three-toed; some walked on four feet, some on only two hind-feet; some had long, dragging tails (Fig. 292), and some short tails, or none at all (Figs. 293, 294).

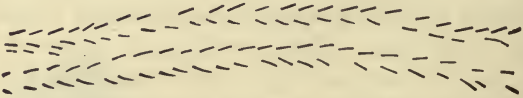

Fig. 291.—Tracks of insects. (After Hitchcock.)

(*c*) As already said, some of these reptiles walked on two legs only, and had only three functional toes, and some were short-tailed or tailless. These have been regarded by some as wingless birds. They were probably all reptiles. One of these wonderful two-legged reptiles is given in Fig. 295.

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* Organic matter decolorizes sandstones.—See page 89.

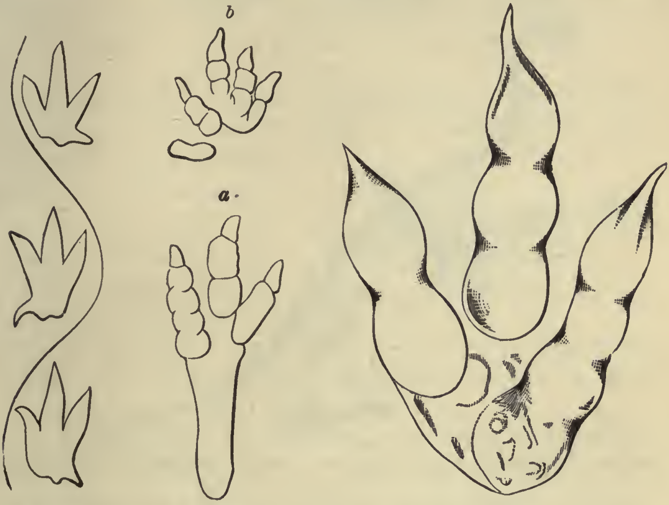

FIG. 292. FIG. 293. FIG. 294.

FIGS. 292–294.—Reptile tracks (after Hitchcock): 292. Gigantitherium caudatum, × $\frac{1}{30}$. 293. Anomœpus minor, × $\frac{1}{8}$: *a*, hind-foot; *b*, fore-foot. 294. Track of Brontozoum giganteum, × $\frac{1}{8}$.

The general conclusion, then, is that all these tracks were those of Dinosaurs and, possibly, Labyrinthodonts. In Jura-Trias times there seems to have been in this place an estuary, into which the tides ebbed and flowed. At low tide, reptiles of many kinds were in the habit of walking on the soft, exposed mud in search of food left by the retreating tide. The incoming tide covered the tracks with fine sediment, and preserved them till now, the sediments, meantime, hardening into stone.

2. **New Jersey Patch.**—In this patch we find the same redness of the sandstone, and therefore the same poverty of fossils. Of this sandstone have been built all

the brownstone houses of New York city. A few bones and teeth of reptiles, however, have been found, and these confirm the conclusions already given. A few tridactyl tracks also have been recently found, similar to those of the Connecticut patch. In Fig. 296 we give a restoration of fish from the New Jersey sandstone.

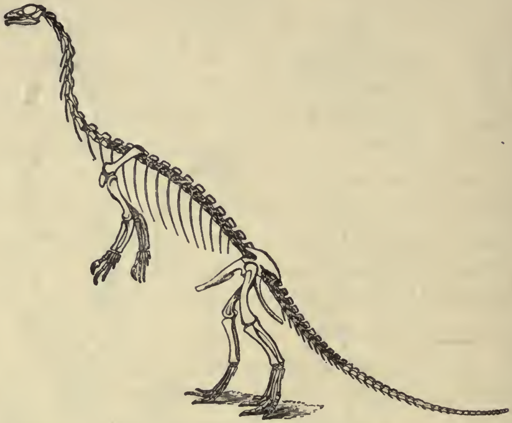

Fig. 295.—Anchisaurus colurus, × $\frac{1}{24}$, from Connecticut sandstone. (After Marsh.)

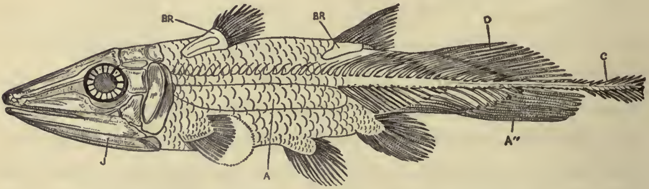

Fig. 296.—Diplurus longicaudatus, × $\frac{1}{8}$. (After Dean.)

3. **Virginia and North Carolina Patches.**—These are very different from the Northern patches. They form the Richmond and Piedmont coal-fields of eastern Virginia (Fig. 297) and the Deep River and Dan River coal-

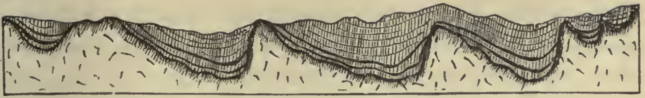

Fig 297.—Section across Richmond coal-field. (After Daddow.)

fields of North Carolina. In connection with the Coal, plants have been found in considerable abundance. They are those characteristics of the Jura-Trias everywhere, viz., ferns, cycads, and conifers. In North Carolina the jaw of a small marsupial has been found about the middle of the series (Fig. 298).

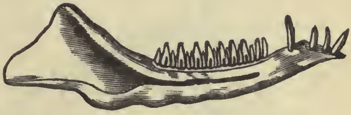

Fig. 298.—Jaw of Dromatherium sylvestre.

The coal of these Jura-Trias fields is of good quality, in thick seams, and easily worked.

4. **Atlantosaur Beds.**—These we describe separately, not only because they are recent discoveries, but also and chiefly because they belong to an entirely different horizon, viz., the uppermost Jurassic passing into the Cretaceous.

In these uppermost Jurassic beds, called *Atlantosaur beds,* from their most abundant and characteristic genus, have recently been found, in Wyoming and Colorado, great numbers of most extraordinary reptiles, the largest yet known, and also a bird and seventeen species of small marsupial mammals.

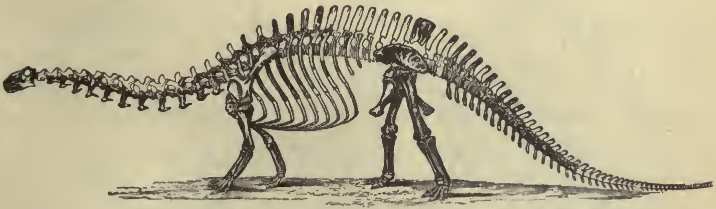

Fig. 299.—Brontosaurus excelsis, × $\frac{1}{100}$. (Restored by Marsh.)

Reptiles.—The extraordinary number of dinosaurian reptiles found here have thrown much light on this order. Some of them were reptile-footed (*Sauropoda*) (Fig. 299), some bird-footed (*Ornithopoda*) (Fig. 300), some beast-

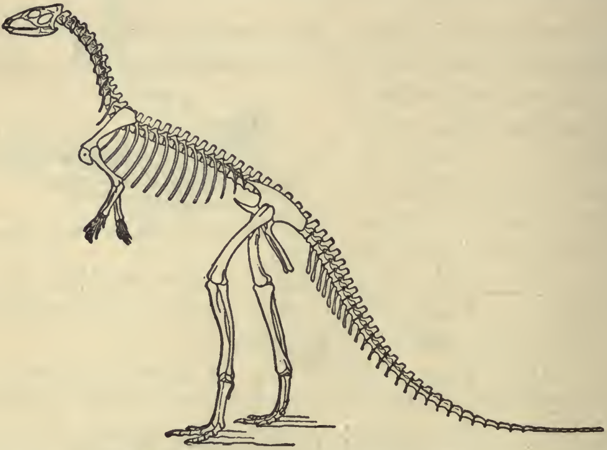

FIG. 300.—Laosaurus, × $\frac{1}{20}$. (Restored by Marsh.)

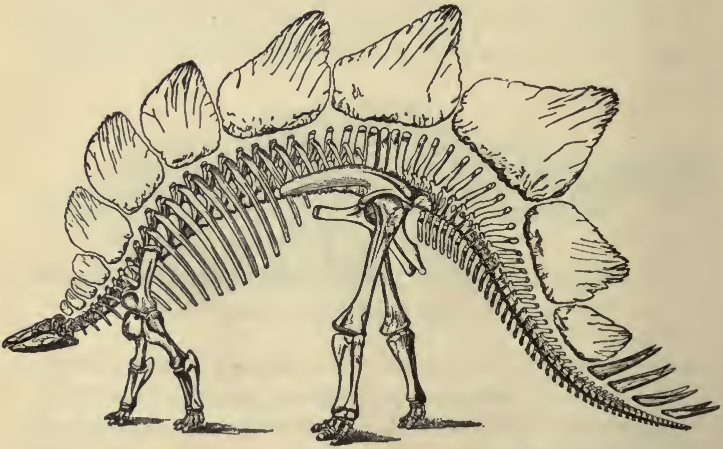

FIG. 301.—Stegosaurus ungulatus, × $\frac{1}{80}$. (Restored by Marsh.)

footed (*Theropoda*), and some curious plate-covered reptiles (*Stegosauria*) (Fig 301). The Ornithopoda and some Theropoda walked almost wholly on their hind-legs in the manner of birds. The size of some of these reptiles is almost inconceivable. A thigh-bone of an Atlantosaur, found by Marsh, was six or seven feet long, and a vertebra of an Amphicœlias, found by Cope, was six feet high to the top of the spinous process. The Atlantosaur has been estimated to have been seventy to eighty feet long!

In the same beds, as already stated, were found the remains of a bird and of seventeen species of marsupials. A figure of one of these is herewith given (Fig. 302).

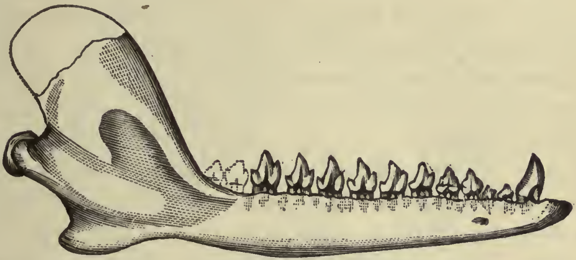

Fig. 302.—Right lower jaw of Diplocynodon victor (after Marsh), outside view—twice natural size.

Disturbances which closed the Jura-Trias Period.—One of the most important changes which occurred at the close of this period was the *formation of the Sierra Nevada Range.* Until that time the Pacific shore-line was east of the Sierra, and the place of this range was a marginal sea bottom receiving sediment. These sediments finally yielded at the close of this period and were folded and swelled up into this great range. Subsequent erosion sculptured it into its present grand forms. Coincidently with this change in the West, there were on the *Atlantic border* outbursts of igneous matter forming the trap ridges. In the *interior region* there was a downward movement of the crust over the whole Plains and Plateau region by which isolated inland seas were changed into the great interior Cretaceous sea. The Sierra Nevada Range is the most conspicuous monument of this period of change, and therefore it may be called the Sierra revolution.

SECTION IV.—CRETACEOUS ROCKS AND PERIOD.

General Characteristics.—The Cretaceous is in some respects a transition to, and a preparation for, the next era. Mesozoic types, such as the great reptiles, the ammonites, etc., continue, but Cenozoic types, like dicotyledonous trees and teleost fishes, are introduced, and the two kinds of types coexisted side by side.

Rock System; Areas.—1. In the *Atlantic border* region, going southward, we find no cretaceans until we reach Long Island. Going south from this, we find a strip running through New Jersey, Delaware, and Maryland, lying directly against the Archæan; then small, isolated patches exposed by erosion in North Carolina, South Carolina, and Georgia. It doubtless extends all along the Southern coast, but is mostly covered with later Tertiary deposits. 2. *In the Gulf border region* it forms a broad, crescentic band, commencing in western middle Georgia, passing through middle Alabama, turning northward through Mississippi and Tennessee, to near the mouth of the Ohio. It underdips the Tertiary of the Mississippi River region, and reappears on its west side (see map, page 272). 3. It thence passes northward, covering nearly the whole *Plains and Plateau region,* though largely concealed by the Tertiary. 4. On the *Pacific* border it is found on the lower foot-hills of the Sierra Nevada in Northern California, and, together with the Tertiary, forming the whole of the Coast Range.

Physical Geography.—From this distribution we can make out with some confidence the condition of the continent in Cretaceous times. 1. North of New York the *Atlantic shore-line* was farther out than now. It crossed the present shore-line near New York, passed along the inner border of the Cretaceous of New Jersey, Delaware, and Maryland, and southward nearly along the limit *of the low countries.* 2. The Gulf shore-line went through middle Alabama, and northward to the mouth of the Ohio, and southward again on the other side of the Mississippi River. 3. Connected with this extended gulf was a great *inland sea* five to six hundred miles wide, covering the whole Plains and Plateau region (with some islands in the Colorado mountains region), and stretching northward probably even to the Arctic Ocean, and thus dividing the continent into two parts, an Eastern or Appalachian continent and a Western or Basin region

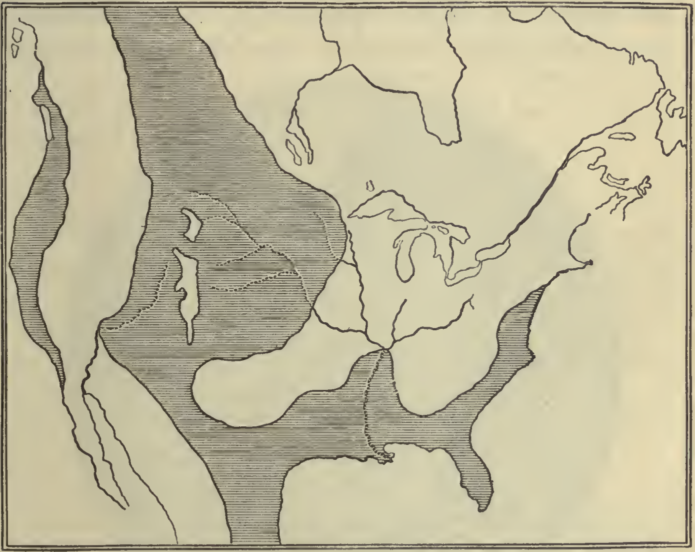

FIG. 303.—Map of North America in Cretaceous times.

continent. The place of the Wahsatch Range was then the western marginal bottom of this interior sea. 4. The *Pacific* shore-line was then east of the Coast Ranges, and its waves beat against the lowest foot-hills of the Sierra. This is shown in the map, Fig. 303.

Character of the Rocks.—In regard to the kind of strata, there are two points worthy of passing mention.

1. **Chalk.**—The period takes its name from the chalk of England and France, which belongs here. *Chalk* is a soft, snow-white, very pure lime-carbonate, scattered through which are nodules of flint. On account of its softness, it is worn into strange, castellated forms. Pure chalk, as described, was until recently, supposed to be confined to England, and France, and middle Europe, but has now been found in the Cretaceous of Texas and the Plains. When examined with the microscope, it seems

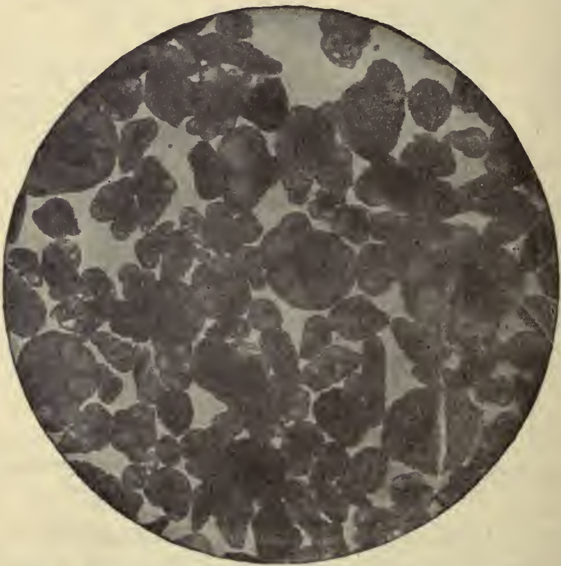

FIG. 304.—View of Iowa chalk under the microscope. (After Calvin.)

to be composed wholly of the remains of low organisms, chiefly foraminifera (Fig. 304). The flints are seen to be composed of shells of Diatoms and spicules of sponges. Now, as already shown (page 117), this is exactly the composition of deep-sea ooze (globigerina ooze), except that the silica has been separated and collected in nodules. It seems probable, therefore, that chalk is a *deep-sea ooze* of the Cretaceous times.

2. **Coal.**—Coal is found, again, in the Cretaceous, both in the United States and elsewhere. But as most of our later coal belongs to a *transition* period between the Cretaceous and the Tertiary, we shall put off the discussion of these for the present.

Life-System; Plants.

So great is the change and the advance in plants at this point, that if we were guided by plants alone, we would say that the Cenozoic era commenced with the Cretaceous. Here the present aspect of field and forest seems to begin, for here were introduced for the first time, and in great numbers, dicotyls, or *ordinary hard-wood trees.* The suddenness of their appearance, however, is due, in part at

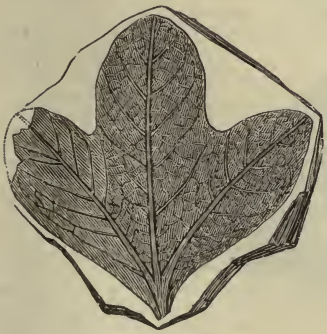

Fig. 305.

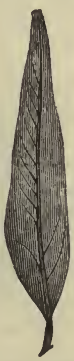

Fig. 306.

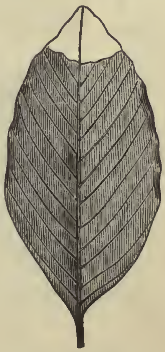

Fig. 307.

Figs. 305–307.—Cretaceous plants (after Lesquereux): 305. Sassafras araliopsis. 306. Salix proteæfolia. 307. Fagus polyclada. All reduced.

least, to a lost interval between the Jura-Trias and the Cretaceous. Of the four hundred and sixty species of plants found in the Middle Cretaceous of the West, four hundred are dicotyls. Nearly all the *genera* of common trees are represented, although, of course, the *species* are extinct. There were then, as now, oaks, maples, willows, sassafras, dogwoods, hickory, beech, poplar, tulip-tree (*Liriodendron*), walnut, sycamore, sweet-gum (*Liquidambar*), laurels, myrtles, etc. A few of these are given in Figs. 305–307.

Animals.

Protozoa.—Though these are found in nearly all the strata heretofore described, we have usually neglected them, because they are inconspicuous. But here in the Cretaceous they are so abundant that they demand attention. Chalk, as already said, is almost wholly made up of foraminifers (Figs. 308–310), and sponges are also extremely abundant. Of the former, some are identical with living species.

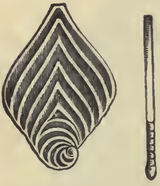
Fig. 308.

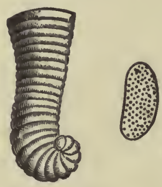
Fig. 309.

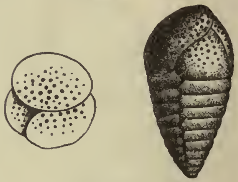
Fig. 310.

Figs. 308–310.—Foraminifera of chalk, magnified: 308. Flabellina rugosa. 309. Lituola nautiloides. 310. Chrysalidina gradata. (After D'Orbigny.)

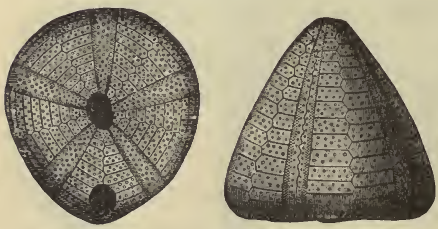
Fig. 311.—Echinoids of the Cretaceous of Europe: Galerites albogalerus.

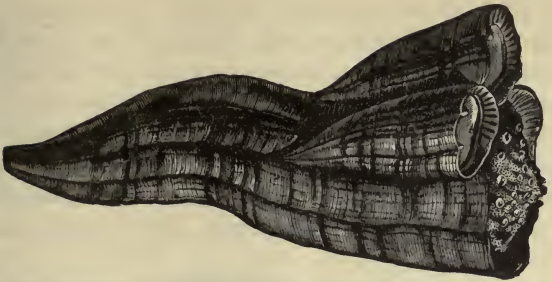

FIG. 312.—Hippurites Toucasiana, a large individual with two small ones attached. (After D'Orbigny.)

Echinoderms are now almost wholly of free forms. The highest echinoids are especially abundant. And, what is remarkable, those from the chalk are very like those still living in deep seas. The reason of this is that deep-sea conditions, and therefore species, change far more slowly than those of shallow water and land.

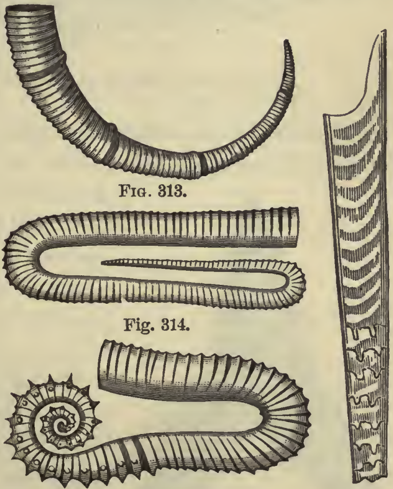

FIG. 313.

Fig. 314.

FIG. 315.

FIG. 316.

FIGS. 313-316.—313. Toxoceras annulare. 314. Hamites attenuatus. 315. Ancyloceras spinigerum. 316. Baculites anceps, × ½. (After Woodward.)

Bivalve Shells.—Among the immense number of bivalve species found here, we mention only the oyster family, of which there are many species, and the strange Hippurite family (Fig. 312). Surely no one, from its general form, would imagine that these latter were bivalves.

Cephalopods.—The Ammonites and Belemnites still continue in great numbers, though they disappear at the end of the Cretaceous; but, in addition to the usual form, the Ammonites take on now the most strange and unaccountable shapes (Figs. 313–316). Some are partly uncoiled, as in *Scaphites* (boat), *Toxoceras* (bow-horn), *Ancyloceras* (curved-horn), *Hamites* (hook); in some, completely uncoiled and straight, as *Baculites* (staff). Sometimes they are coiled spirally, like a gasteropod, as in *Turrulites.* But for the complexity of the suture, no one would imagine a baculite or a turrulite to belong to the Ammonite family. It is probable that rapidly changing and unfavorable conditions tend to produce new and strange forms. The Ammonite family were on the point of becoming extinct.

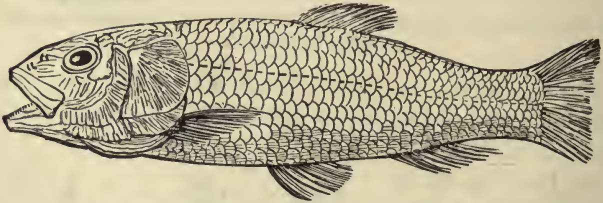

FIG. 317.—Cretaceous fishes—Teleosts: Osmeroides Mantelli.

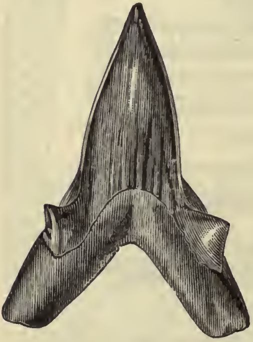

FIG. 318—Cretaceous fishes—Sharks: Otodus. (After Leidy.)

Fishes.—Here we note another great step in the progress of life. The *Teleost* fishes, the vastly predominant kind at the present day, are here first introduced, and almost immediately become abundant. The *Ganoids* at once become very subordinate. The sharks, however, are abundant and of large size, and of the highest kind, viz., Squalodonts, or true sharks (Fig. 318).

Reptiles.—If, in Europe, reptiles seem to have culminated in the Jurassic, in America they seem to have culminated in the uppermost Jurassic and Cretaceous. The great interior Cretaceous sea and adjacent land seems to have swarmed with marine and land reptiles of incredible size. All the kinds already spoken of under the Jurassic were found also in the Cretaceous, and in addition, one order, the *Mosasaurs*—wholly characteristic of the Cretaceous. The accompanying schedule will give some idea of the number of species, and the kinds, of these reptiles. We shall not again describe most of these, but only mention a few interesting points :

Plesiosaurs,	13	species.
Dinosaurs,	21	"
Crocodilians,	14	"
Pterosaurs,	7	"
Chelonians,	48	"
Mosasaurs,	50	"
Total,	153	"

The *marine saurians* were represented in America only by the long-necked kinds (*Plesiosaurs*); but these were numerous, and some greatly surpassed in size any European species, attaining even fifty feet in length.

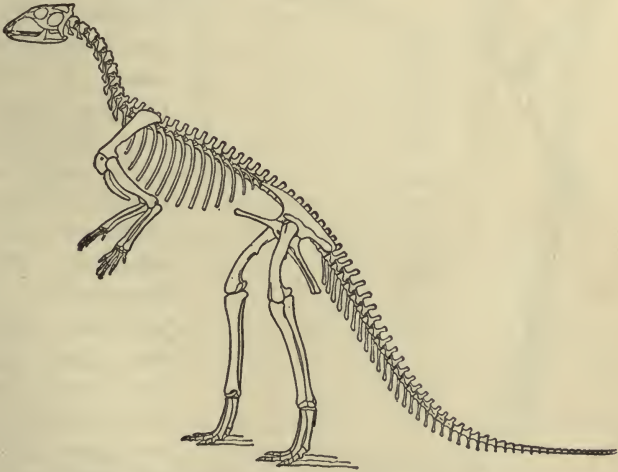

FIG. 319.—Hypsilophodon, × $\frac{1}{18}$. (Restored by Marsh.)

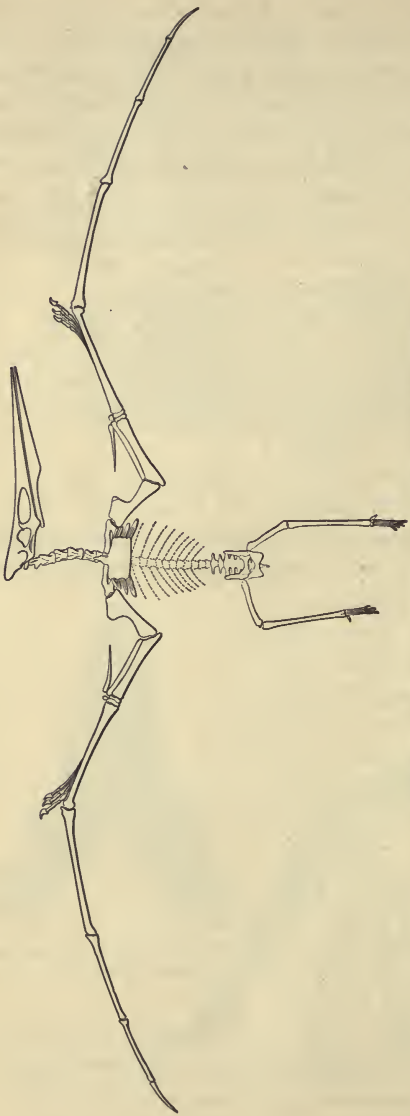

Fig. 320.—Pteranodon ingens, × $\frac{1}{30}$. (Restored by Williston.)

The *Dinosaurs* were also abundant, and of great size. The restored skeleton of a European species (Fig. 319) will give some idea of their general appearance and size.

The *Pterosaurs,* or winged saurians, of America, were of enormous size in the Cretaceous, some attaining an alar extent of twenty-five feet; but a striking peculiarity of them was the entire absence of teeth. On this account they have been put into a distinct family, *Pteranodonta* (toothless, winged). The Pteranodon ingens had toothless jaws, four feet long, and wings twenty-two feet from tip to tip (Fig. 320).

But the *Mosasaurs* were the most abundant and also the most characteristic of all, being found only in the Cretaceous. At least fifty species are known, and the remains of 1,400 are now in the Peabody Museum at Yale University. These were long, slender, almost snake-like in form, with limbs in the form of powerful paddles (Fig. 321). They were, therefore, entirely marine in habits, and wholly incapable of locomotion on land. The head was slender, and armed with large, recurved teeth. They were allied most nearly to lizards, and therefore might be called huge sea-lizards; but, like most early animals, they were a generalized type, connecting also with other orders, especially snakes. Some species were seventy to eighty feet long, and had teeth seven inches in length.

Birds.—The history of the discovery of fossil birds is interesting. In 1862 the wonderful Jurassic bird, *Archæopteryx,* already spoken of (page 338), was discovered. But this stood alone, without links connecting it with typical birds. In 1870 commenced the wonderful series of discoveries by Marsh, mostly in the Cretaceous of the West, which served largely to fill up this gap. About twenty species of Cretaceous birds have been described by him. Of these, about one half were ordinary *water-birds,* allied to the Rails, Divers, Cormorants, etc., though of different genera, but the other ten were wonderful

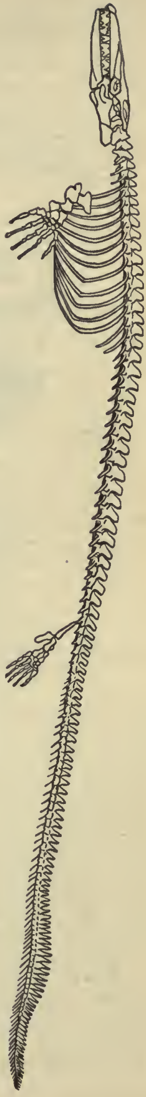

Fig. 321.—Edestosaurus velox. (Restored by Williston.)

Toothed-birds, wholly different from anything now living. These *Toothed-birds* were, again, of two types. Those of the one class (of which the *Hesperornis* may be taken as a type) were flightless swimmers and divers, of great size (five to six feet long), with scarcely a rudiment of wings. Those of the other class (of which the *Ichthyornis* is the type) were smaller in size, but powerful fliers. The *Hesperornidæ* had teeth in grooves—a lower condition. The *Ichthyornidæ* had teeth set in distinct sockets. We give herewith (Figs. 322, 323) Marsh's restorations of these two types.

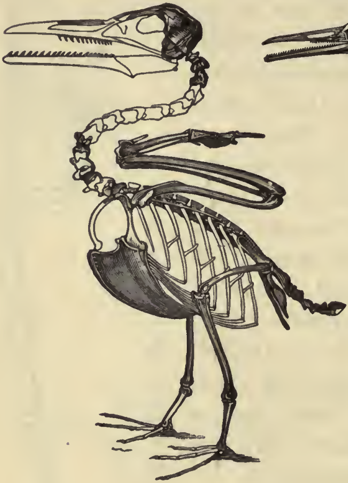

FIG. 322.—Ichthyornis victor, × $\frac{1}{3}$. (Restored by Marsh.)

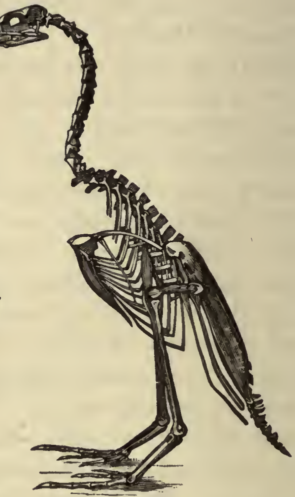

FIG. 323.—Hesperornis regalis, × $\frac{1}{15}$. (Restored by Marsh.)

Mammals.—We found *marsupials* somewhat abundant in the Jurassic, though no true typical mammals. It is, therefore, somewhat remarkable that no mammal of any kind has yet been found in the Cretaceous, except in the Laramie, which may be regarded as a transition to the

Tertiary. Yet, doubtless, marsupials did exist throughout the Cretaceous, because they existed in the Jurassic, and again in the Tertiary, and even now; and it is a law in paleontology that a form, *once become extinct, is never revived.* Nature never repeats herself. Doubtless, marsupials existed in some part of the earth, and their remains will yet be discovered.

General Observations on the Mesozoic.

That this was, in a most wonderful degree, an age of reptiles, is easily shown. In the world, at the present time, there are about six great reptiles—one crocodile in Africa, two gavials in India, three alligators in America, North and South—all of them in tropical and sub-tropical regions, and none more than twenty to twenty-five feet long. Now, take a single epoch, the Wealden—comparable, therefore, with the present—and only the small area of England. There were in England, in Wealden times, five or six dinosaurs, twenty to sixty feet long; ten or twelve marine saurians and crocodilians, ten to fifty feet long, besides pterodactyls, turtles, etc. Again, in America, in Cretaceous times, leaving out the turtles, there were more than one hundred species of land, marine, and flying reptiles, the larger number of which were greater than any living crocodile. In the epoch of the Atlantosaur beds, reptiles were probably as numerous, and certainly of still greater size. These are the known; but, of course, the findings are but a small fraction of the actual fauna. The fact is, reptiles were rulers in every realm of Nature. They stood in place of beasts, as rulers of the land; of whales and sharks, as rulers of the sea; and in place of birds, as rulers of the air. They impressed their reptilian character—the fashion of the court—on all other higher classes; the mammals were reptilian, and so were the birds.

Disturbances which closed the Cretaceous Period and Mesozoic Era.—Remember that during the Cretaceous a great sea, stretching from the Gulf of Mexico to the Arctic Ocean, covered the whole Plains and Plateau region, and divided the continent into two continents—an eastern and a western. Now, at the end of the Cretaceous, this great sea was abolished by the gradual upheaval of this region, and the continent became one. At the same time the western marginal bottom of the great interior sea yielded to horizontal pressure, and was crushed together and swelled up into the *Wahsatch Range.* At the same time, also, the *Colorado Mountains,* which had been a line of islands in the Cretaceous sea (map, page 349), were pushed up, and the Cretaceous strata sharply uptilted on the flanks. At the same time, also, the *Uintah Mountains* seem to have been born. Such great changes in physical geography imply corresponding changes in climate, and in fauna and flora. We ought to, and do, indeed, find the animals and plants very different in the next age (Cenozoic).

Laramie or Transition Epoch.

The abolition of the great Cretaceous sea, and the unification of the continent, as we have said, were produced by the upheaval of the Plains and Plateau region. When completed, the Plateau region was occupied by great fresh-water *lakes,* which we shall describe hereafter. But this change took place gradually, passing through intermediate stages of brackish-water seas. When marine conditions prevailed, it was undoubtedly Cretaceous; when fresh-water conditions were established, it was undoubtedly Tertiary. But what shall we call the intermediate time of brackish water? This is evidently a transition period. It is the *lost interval* between the Cretaceous and the Tertiary in Europe, recovered here.

As we might expect, we find Cretaceous types lingering and Tertiary types coming in, and the two coexisting side by side. The Cretaceous dinosaurs linger, but the Tertiary plants are introduced. The paleo-zoölogists are disposed to ally it with the Cretaceous, and the paleobotanists with the Tertiary. It is really a *transition* between the two.

Plants.—Vegetation was luxuriant at this time. More than three hundred species of dicotyls have been described here. But, as the types are wholly Tertiary, we shall illustrate them under that head.

Coal.—The conditions seem to have been favorable, not only for luxuriant vegetation, but for its preservation as coal, and nearly all the Cretaceous coal mentioned on page 351 belong to this transition period, and have therefore been often put in the Tertiary. Next to the Coal-measures, this is the great coal-bearing period of the United States. The largest fields are in the Plains and Plateau region, viz.: 1. A large field, the Marshall coal-field, in western Kansas, about 5,000 square miles. 2. Another large field, in New Mexico, of equal size. 3. A third large field, in Dakota, extending into British America. 4. A large and valuable field, in the Plateau region, on the Laramie Plains, stretching through Wyoming to the borders of Utah. These altogether can not be less than 50,000 square miles. On the Pacific slope several coal-fields, probably of the same age, are found: 1. Mount Diablo and Corral Hollow field. 2. Seattle, Carbon Hill, and Bellingham Bay field. 3. Nanaimo or Wellington field on Vancouver's Island. Coal is also found in Arizona and in southern California, but the age is not known.

All the later coals are often called lignites, but much of it is an excellent coal, scarcely distinguishable from carboniferous coal. We herewith present in tabulated form all the principal coal-fields of the United States:

Carboniferous.	Appalachian. Central. Western. Michigan.	192,000.
Jura-Triassic.	Eastern Virginia. North Carolina.	500 (?).
Laramie.	Plains and Plateau. Pacific Slope.	50,000 (?).

Animals—Reptiles.—A large number of the most extraordinary reptiles yet discovered (Fig. 324), and also several species of small marsupial mammals, are found in these uppermost Cretaceous beds.

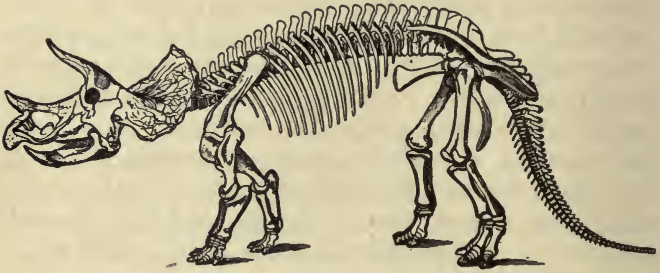

Fig. 324.—Triceratops prorsus, × $\frac{1}{80}$. (After Marsh.)

CHAPTER V.

CENOZOIC ERA.—AGE OF MAMMALS.

THIS is reckoned a primary division—*an Era*—because there is just here a very general break in the rock-system, and a very great change in the life-system. It is also called *an Age*, because a new and higher dominant class appears here. In Europe, the unconformity is universal, and, as might naturally be expected, there is an apparently *sudden* change in the life-system. But in America the Laramie is not only everywhere conformable with the Cretaceous beneath, but in many places also with the Tertiary above; so that the record is almost continuous. And yet, at the same level, viz., between the Laramie and the Tertiary, we find an enormous change of life-forms. It is impossible to account for this, unless we admit that the steps of progress were quicker at this time.

General Characteristics.—In a geological sense, modern history commences here. Modern types of animals and plants, modern aspects of field and forest, were fairly inaugurated. Now was established in broad outline the present order of things—the present rulers on land (except man), in the seas, and in the air; the present adjustment of the orders of animals and plants. Hence the name, "*Cenozoic.*" Some of these characteristics, however, especially the introduction of Dicotyls, and therefore the aspect of forests, were anticipated in the Cretaceous. As there is now a new and higher dominant class, viz., mammals, reptiles must decline in number and size, and thus seek safety in a subordinate position.

Subdivisions.—The Cenozoic era and Mammalian age is divided into two periods—*Tertiary* and *Quaternary.* In the Tertiary all the mammalian species are extinct, but many invertebrate species are still living, and the percentage of living species increases with time. In the Quaternary, on the contrary, nearly all the invertebrate species, e. g., mollusks, still survive, and some of the mammalian species also survive. These facts are shown in the diagram (Fig. 325). The space above the lines of mollusks and mammals shows proportion of extinct, and below the line, of living, species. The dawn of living species of shells is with the beginning of the Tertiary; the dawn of living mammalian species is in the Quaternary. Both curves show increasing percentage of living species with time.

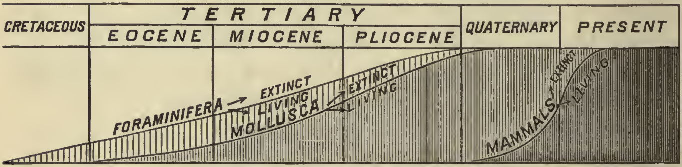

Fig. 325.—Diagram showing the relative number of species living and extinct.

Section I.—Tertiary Period.

As already stated, the dawn of living molluscan species is in the earliest Tertiary, and thenceforward the percentage of living species steadily increases; but no living mammalian species are found there.

Subdivisions.—The subdivisions of the Tertiary period into epochs are founded on this percentage of living molluscan species. It is thus divided into three epochs—Eocene, Miocene, and Pliocene. If we find a stratum which contains not more than 5 to 10 or 15 per cent. of its shells still living in neighboring seas or lakes, we call it *Eocene;* if 15 to 40 or 50 per cent., we call it *Miocene;* if 50 to 80 or 90 per cent., we call it *Pliocene.* This is graphically illustrated in the diagram (Fig. 325).

Tertiary Period.	Pliocene,	50 to 90	per cent.	living.
	Miocene,	15 " 50	"	"
	Eocene,	5 " 15	"	"

Rock-System.

Areas in the United States.—1. On the *Atlantic border,* going south, we find no Tertiary until we reach New Jersey. Thence to Georgia there is a band of Tertiary strata about a hundred miles wide, resting in New Jersey on the Cretaceous, but elsewhere against the Archæan gneiss. It constitutes what are called the low countries of the Southern Atlantic States. The rivers, in passing from the gneissic to the softer Tertiary, make falls or rapids. Here, therefore, is the head of navigation of the Southern rivers, and, therefore, also the position of many important towns. Richmond and Petersburg, Virginia; Raleigh, North Carolina; Columbia, South Carolina; Augusta, Milledgeville, and Macon, Georgia—are thus situated.

2. The same broad strip of Tertiary lowlands *borders the Gulf,* resting there, however, on the Cretaceous (see map, page 272), expands northward to the mouth of the Ohio River, and sweeps southward about the western border of the Gulf into Mexico.

3. On the *Pacific border* we find Tertiary with Cretaceous, forming the Coast ranges of California and Oregon. All these border Tertiaries—Atlantic, Gulf, and Pacific—are *marine* deposits.

4. But in the interior regions—i. e., Plains, Plateau, and Basin—we have extensive fresh-water deposits. Some

of these are Eocene, some Miocene, some Pliocene. The Eocene deposits are in the Plateau region north and south of the Uintah Mountains. The Miocene and Pliocene deposits are in the Plains and the Basin regions.

These fresh-water deposits of the West are imperfectly lithified, and therefore are sculptured by erosion into the curious forms called *Mauvaises Terres,* as already explained (page 248, Fig. 152).

Physical Geography.—It is easy, from the distribution just given, to reconstruct the physical geography of the American Continent during the Tertiary. It is simply a restatement in another form of what we have already said. On the *Atlantic border* the New England shore-line was *farther out* than now, because we have no Tertiary deposits exposed along that coast. The Tertiary shore-line crossed the present shore-line about New York, and thence passed along the line of limit of the Tertiaries of the Southern Atlantic States, the waves beating there against Archæan shore-rocks. On the *Gulf border* the north shore of the Gulf did not reach quite so far as in Cretaceous times (see map on page 272), but the Gulf waters covered all the flat lands about the Gulf, beating here on Cretaceous rocks; extending north, as an embayment to the mouth of the Ohio River, and then swept southward, covering a broad strip on the west. The Upper Mississippi (if it existed at all) and the Ohio emptied by separate mouths into the embayment. On the *Pacific border* the waves of the Pacific beat against the foot-hills of the Sierra, the place of the Coast Range being then a *marginal sea-bottom.* Fig. 326 shows the American continent in Early Tertiary.

The *interior region* was occupied by enormous lakes. During the Eocene, the lakes were in the Plateau region; during Miocene and Pliocene times, in the Basin on the one side and the Plains on the other.

Coal.—Lignite is found again in the Tertiary, especially in the Miocene. The Coos Bay coal of Oregon, and the imperfect seams of the Contra Costa Range, California, are Miocene. The Ione brown coal of Amador County, California, is still more recent, probably Pliocene.

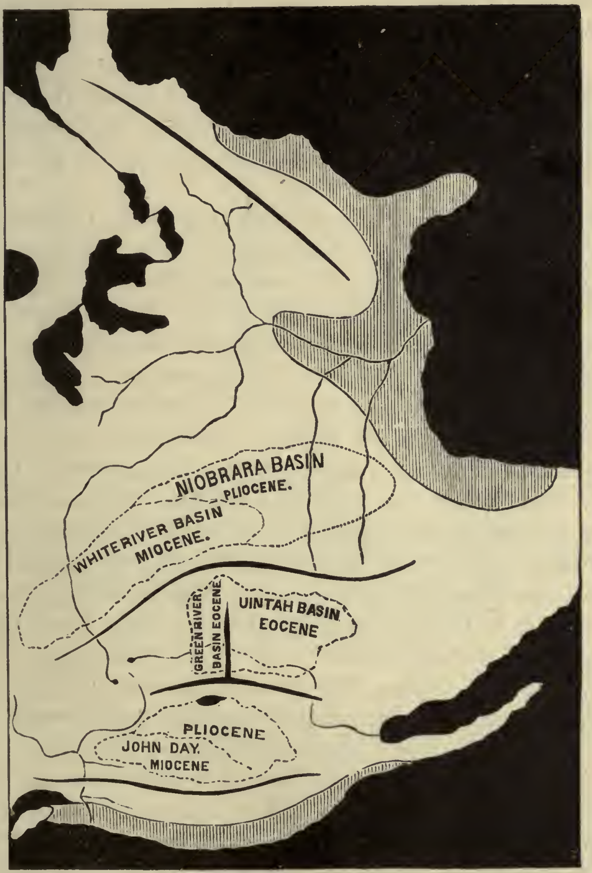
NIOBRARA BASIN
PLIOCENE.
WHITERIVER BASIN
MIOCENE.
GREEN RIVER
BASIN EOCENE
UINTAH BASIN
EOCENE
PLIOCENE
JOHN DAY
MIOCENE

Fig. 326.—The American continent in Early Tertiary.

Life-System.

General Character.—This era is called Cenozoic because modern life in its main features commences here. We are therefore prepared to find that, among plants and lower animals, the general similarity to present forms is so great that the difference would hardly be recognized by the popular eye. We must touch very lightly on these lower forms.

Plants.—We have already seen that in the Cretaceous many familiar genera of forest-trees were introduced. In fact, so far as trees are concerned, the Cenozoic might be said to commence in the Cretaceous. In the Tertiary nearly all the genera are the same as now, although the species are mostly different. The genera are the same as now, *but not in the same localities.* On the contrary, the same genera grew much farther north than now. The vegetation indicated a much warmer temperature than now. In Eocene times, palms and other tropical plants grew all over Europe, and the mean temperature seems to have been 75° to 80°. In Miocene times, evergreens, like those now about the shores of the Mediterranean, flourished even to Lapland and Spitzbergen. The mean temperature of Europe was 16° to 20° higher than now.

In America, during the Eocene, palms and figs and evergreens, in Dakota, show a temperature there about that of Florida now. In Miocene times, Sequoias very like the Big tree and the Redwood of California, and taxodiums, and magnolias—almost, if not quite, identical with the cypress of the Southern swamps and the *Magnolia grandiflora* of Southern forests—were abundant in Greenland. The temperature of Greenland was then at least 30° higher than now. It is easy to see that polar ice could not have existed, and Arctic expeditions would have been an easy matter, if man had lived at that time. We give some figures of Tertiary plants (Figs. 327–332).

But if these highest plants were exceptionally abundant, so were also the lowest of all, viz., the unicelled diatoms. The great deposits of diatomaceous earths found in many parts of the world are Tertiary. In the United States the best known localities are near Richmond, Virginia, and in California. These deposits are many miles in extent, and thirty to one hundred feet thick, and made up wholly of the silicious shells of these microscopic plants.

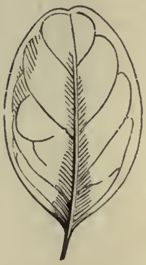
Fig. 327.

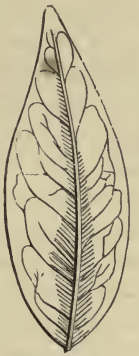
Fig. 328.

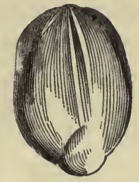
Fig. 329.

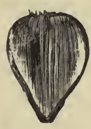
Fig. 330.

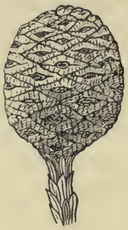
Fig 331.

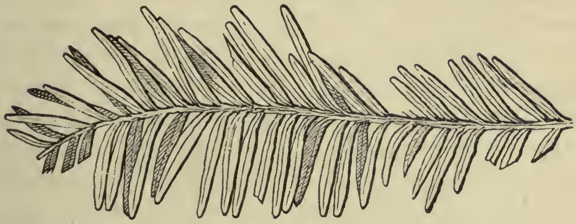
Fig. 332.

Figs. 327–332.—American Tertiary plants (after Safford and Lesquereux): 327. Quercus crassinervis. 328. Andromeda vaccinifoliæ affinis. 329. Carpolithes irregularis. 330. Fagus ferruginea—nut. 331. Fruit of Sequoia Langsdorfii (after Heer). 332. Leaf of Sequoia Langsdorfii (after Heer).

Animals.

The similarity in general appearance of most Tertiary invertebrates to living species is so great that we shall only draw brief attention to a few interesting points.

Mollusca.—We are all doubtless interested in the *family* history of the oyster. The family commenced in the Jurassic, increased in the Cretaceous, and culminated in the Tertiary, and then declined. The *Ostrea Georgiensis* and the *Carolinensis* of the Eocene were several times larger than their modern representative. The *Ostrea Titan,* of the Pacific coast Miocene, was still larger, being thirteen inches long, eight inches wide, and six inches thick. Lest some may regret inconsolably the passing away of these magnificent oysters before the advent of man, I hasten to remind them that what has been lost in size has probably been gained in flavor.

Insects.—Insects are always closely associated with land vegetation, and the kinds of the one are determined by the nature of the other. Now, for the first time, the highest flowering plants are abundant, and now, for the first time also, all orders of insects, even the highest flower-loving kinds, such as butterflies, bees, ants, etc., are abundant (Fig. 333). On account of the greater warmth and moisture, both vegetal and insect life were fuller even than now. We select a few examples of findings, by means of which we may reproduce in imagina-

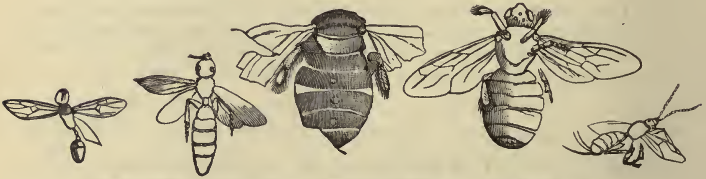

FIG. 333.—Ants and bees of European Miocene. (After Heer.)

tion the conditions of things which prevailed in Tertiary times:

1. In the Miocene fresh-water deposit of Oeningen, a layer two feet thick is black with the remains of insects. It is also full of leaves. About nine hundred species of insects and five hundred species of plants have been made out. The larger number of insects are beetles and ants. We may imagine that in Miocene times there was at Oeningen a lake surrounded with a thick forest, whose leaves were scattered on the waters and cast upon the shore. Beetles and flying ants, essaying to fly over the lake, were beaten down by the winds and also cast on the shore. These remains were covered up by mud, and thus preserved.

2. On the shores of the Baltic, bits of amber, derived from Miocene strata outcropping beneath the water, are continually thrown up by the action of the waves. In these are found, sealed up, and in transparent pieces clearly visible, great numbers of insects, often in an exquisitely perfect state of preservation. About eight hundred species of insects and one hundred and fifty species of plants have been described. The insects are mostly winged ants and flies. Amber is known to be the fossil gum of a pine (*Pinus succinifer*). We may imagine, then, that in Miocene times, in the region now occupied by the southern Baltic, there was a forest, among the trees of which the *Pinus succinifer* abounded. From these trees a semi-liquid, sticky gum exuded in tears, on which insects alighting stuck fast, and were covered by later exudations.

3. In Auvergne, France, there is a Miocene fresh-water deposit, one layer of which, two to three feet thick, is almost wholly composed of the cast-off cases (*indusia*) of caddis-worms, and is therefore called indusial limestone. The caddis-worm (larva of the caddis-fly) of to-day is a wingless creature, living wholly in the water. It has the

curious habit of gathering bits of wood, small dead shells, or even grains of sand, and webbing them together to form a cylindrical hollow case in which it lives. When it wishes to walk about, it puts out the head and legs for that purpose, as seen in the figure. These cases are left when the worm changes into the caddis-fly. We may imagine, then, that in Auvergne, in Miocene times, there was a lake in which lived countless generations of caddis-worms, and their cast-off cases accumulated until a deposit, two to three feet thick, was produced.

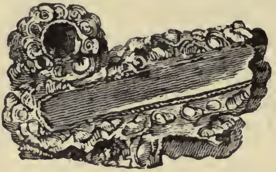

Fig. 334.—Fragment of indusial limestone (natural size), showing the caddis-worm cases.

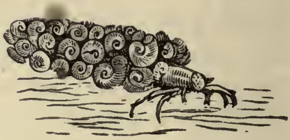

Fig. 335.—Recent caddis-worm, with its case.

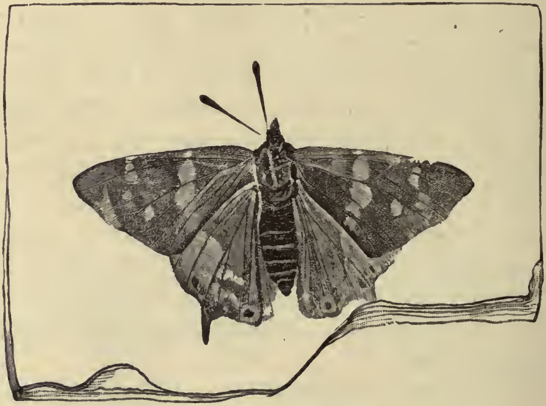

Fig. 336.—Prodryas Persephone. (After Scudder.)

4. Only very recently a remarkable American locality has been discovered. At Florissant, Colorado, a fresh-water deposit of Upper Eocene or Lower Miocene age has been found, one layer of which is black with the remains of insects of all kinds. Scudder has identified more than a thousand species. We give here (Fig. 336) a beautifully preserved butterfly from this locality. Here, then, we have phenomena like those at Oeningen, and explained in the same way.

Fishes.—In general appearance, Tertiary fishes are much like those of the present day. Then, as now, Teleosts vastly predominated (Fig. 337), and Ganoids were nearly extinct. Then, as now, sharks were among the chief rulers of the seas. In fact, they seem to have culminated in the Tertiary. The Eocene strata of the Atlantic border are in places full of sharks' teeth, some of which are of incredible size. We have seen one of these, of the kind represented in Fig. 338, which would more than cover a page of this book, being nearly seven inches long and six inches wide. The original possessors of such

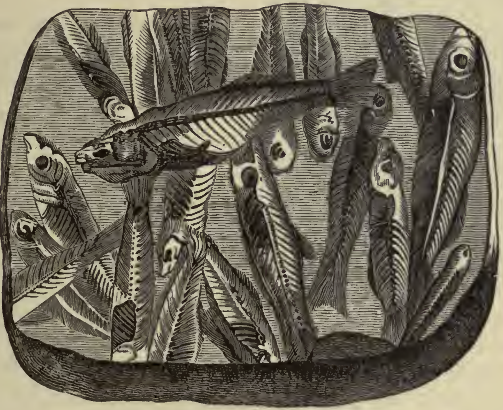

FIG. 337.—Tertiary fishes—Teleosts : Lebias cephalotes, Miocene.

teeth could hardly have been less than sixty to seventy feet long.

Reptiles.—The reign of reptiles is past. The Reptilian dynasty is overthrown. This class no longer occupies a prominent place in history. In geological history the ruling class is always the *fittest* to rule, which can not always be said of the reigning families in human history.

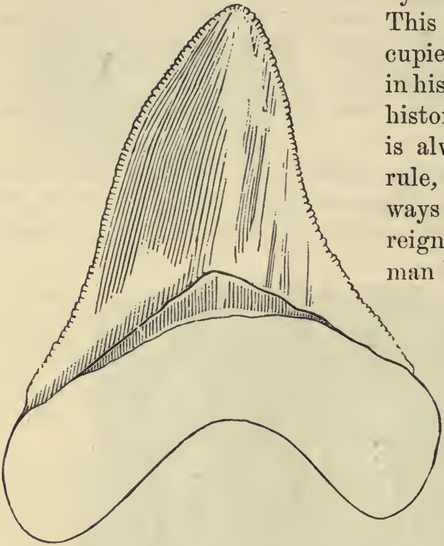

FIG. 338.—Tertiary fishes—Sharks: Carcharodon megalodon, × ½. (After Gibbes.)

The great characteristic reptiles of the Mesozoic are all extinct. Among great reptiles, the crocodilians alone remain. The reptiles of the Tertiary are of the same families as now exist, viz., crocodiles, turtles, snakes, lizards, frogs, toads, and salamanders. Snakes seem a low type, and yet were introduced only in the Tertiary. But they are not low in the sense of *undeveloped.* They have developed *backward*—they are an example of a degraded type. The tailless amphibians (frogs and toads) are undoubtedly the highest among amphibians; for they pass through the tailed stage (tadpole) in embryonic life. These tailless amphibians were introduced first in the Tertiary. The biggest known turtle (*Colossochelys*) was found in the Miocene of India. Its shell was twelve feet long, eight feet wide, and seven feet high.

Birds.—It will be remembered that the earliest bird known (the Jurassic Archæopteryx) was also the most reptilian. In the Cretaceous we found both reptilian *toothed-birds* and ordinary *water-birds*. Now, in the Tertiary, as in the present, all the reptilian birds had disappeared, and only typical birds remain ; and not only water-birds, but also the highest, viz., land-birds. In other words, the bird-class had now fairly separated itself from the reptilian, and the connecting links were all destroyed.

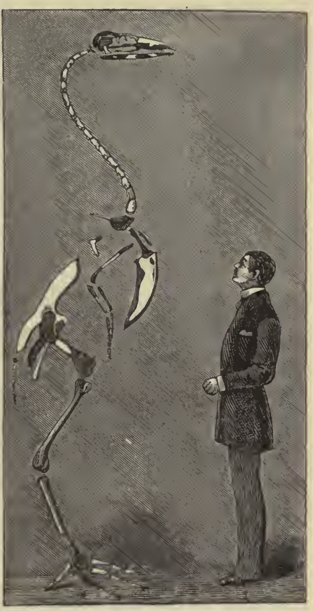

FIG. 339.—Restoration of Gastornis Eduardsii. (After Meunier.)

Nearly all the families of birds now existing have been found in the Tertiary, but also a few of strange forms. The *Gastornis*, of the Eocene of Paris (Fig. 339), was a huge bird, ten feet high, and a curious connecting link between waders and ostriches. Besides these curious forms, many birds have been found, in the Tertiary of this country and in Europe, similar to those still living. But in France, especially, the birds, like the plants and insects, show a decided tropic climate. Parrots, trogons, ibises, secretary-birds, and flamingoes inhabited France at that time.

Mammals.

Remember that, although marsupials or reptilian mammals were found in Jura-Trias, and doubtless continued through the Cretaceous, true, ordinary, or typical mammals first appear in the lowest Tertiary, and immediately became the dominant class.

Some Preliminary Remarks.—Before describing the Tertiary mammals, there are some points requiring notice:

1. The *suddenness of their appearance* is very remarkable. In the very lowest Tertiary, without warning and without apparent progenitors, true mammals appear in great numbers, in considerable diversity, and even of the highest order—Primates, or monkey tribe. Now, in Europe, where there is a decided break and a lost interval, this is not so surprising; but even in America, where the Laramie passes without break into the Tertiary, the same is true. At a certain level the great dinosaurs disappear, and the mammals take their place. A new dynasty and a new age in history commence. It is impossible to account for this by natural causes, *unless we admit times of rapid progress.* In addition to this, we must also admit that the apparent sudden appearance in a particular place is largely *due to migration.*

2. We have said that they appeared in great numbers and considerable diversity. All the great branches of the Mammalian class were represented in the first fauna—herbivores, carnivores, and primates or monkeys. Yet these were not so distinctly separated as now. *They were all generalized types.* If we represent all the orders and families of mammals as branches and sub-branches of one main trunk, then, as we go backward in time, these become less numerous and less widely separated. In the earliest Eocene the branches are few and very near together. The carnivores are but slightly separated from the herbivores—in fact, they are both omnivores. The monkeys, also, were not yet fairly separated as typical monkeys. They are therefore called Prosimiæ, or progenitors of the true monkey. Manifestly, if these branches

have a common origin, it must be sought still lower, probably in the Laramie.

Tertiary Lake-Deposits of the West.

Nowhere in the world is there so complete a series of Tertiary deposits and of Tertiary mammals as in the lake-deposits of the Plateau and Plains and Basin regions already spoken of (page 365). We shall therefore take most of our illustrations from these.

Eocene Lake-Deposits.—In the Lower Eocene deposits—viz., Puerco beds and Wahsatch or Coryphodon beds—have been found nearly one hundred species of mammals, including carnivores, herbivores, insectivores, and monkeys. Perhaps the most remarkable and characteristic animals of the lower Tertiary were the *Coryphodonts.* These were huge animals with very small brains, plantigrade feet, slow, awkward movements, and very generalized structure.

In the Middle Eocene *Bridger beds,* mammalian life was even still more abundant. More than one hundred species are known, and these are, of course, but a fraction of what actually existed. Perhaps the most remarkable animals of this time were those of the Dinoceras family. The Dinoceras may be taken as a type of the family. This was a heavy-built, sluggish-moving animal of elephantine size, with a most singular conformation of head, which was armed with three pairs of horns and a pair of huge tusks, as shown in Fig. 340. Some are supposed to have had a head five feet long.

During the Eocene, also, Marsh finds the earliest progenitors of the horse. In the early Eocene is found the *Eohippus,* an animal which had three hoofed toes on the hind-feet and four perfect hoofed toes and a rudimentary fifth toe on the fore-feet. This was followed in the Middle Eocene by the *Orohippus,* similar to the other, except that the fifth rudimentary toe is dropped. These animals were about the size of a fox.

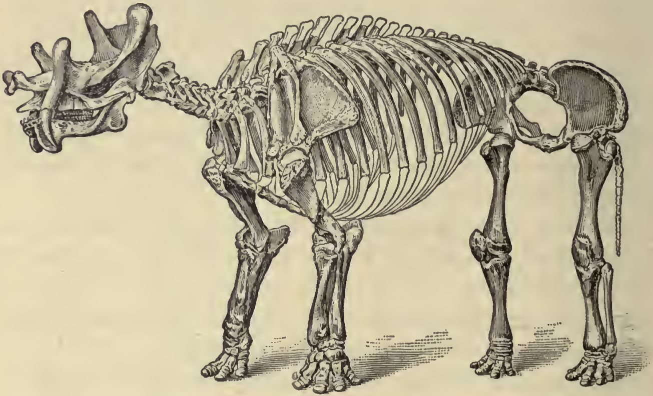

FIG. 340.—Tinoceras ingens. (After Marsh.)

Miocene.—The Eocene lake-deposits are in the Plateau region, the Miocene and Pliocene are in the Plains and Basin region. The first thing to be noted here is the complete change of species. It is worthy of note that in the Miocene many existing *families* (not species), such as the rhinoceros family, the camel family, the deer family, the dog family, and the cat family commenced to exist. Among the many forms which occur here we can only mention the most remarkable. In this respect, certainly, the *Brontothere* stands first. This animal was still larger than the tinoceras, and connects the latter with the rhinoceros. The peculiar saddle-shaped head was three feet long. It had only three toes behind, like the rhinoceros, but four in front.

In the Miocene the horse family is represented by the *Mesohippus* and *Miohippus*. These had three toes on the hind and the fore foot, and were about the size of a sheep. True tridactyl horses commence here.

Pliocene.—Here, again, we have a great change of mammalian species. The animals are much more like existing species. If many existing *families* commenced in the Miocene, we find many existing *genera*, such as the horse (*equus*), the camel (*camelus*), the elephant (*elephas*), etc., commencing in the Pliocene. Great numbers of the horse family, *Protohippus*, *Pliohippus*, and finally Equus, great numbers of the camel family, several elephants and mastodons, roamed in herds over the American Continent. The Protohippus was a three-toed horse, like the Miohippus, but the side-toes were shorter. It was very similar to the Hipparion of Europe (Fig. 343). The Pliohippus was very horselike. It was *one-toed*, like a true horse, the two side-toes having dwindled to splints.

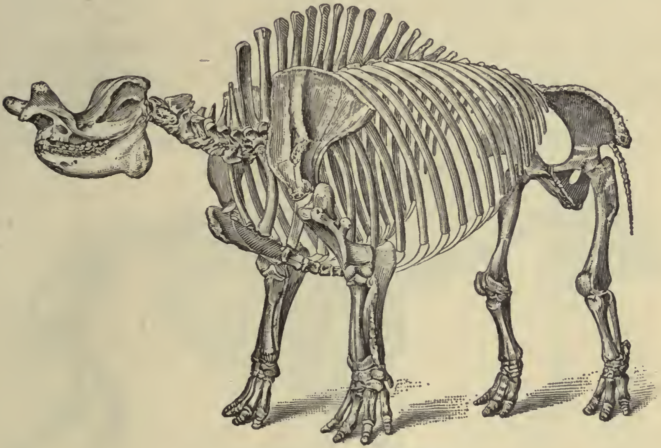

FIG. 341.—Brontops. (After Marsh.)

Foreign Localities.

Paris Basin.—Among foreign Tertiary deposits the most celebrated is the Eocene basin of Paris. The streets of Paris teem with a living generation of men and animals.

Its cemeteries are full of the remains of a former generation. But a little deeper down we find another cemetery full of the remains of extinct animals of strange forms. The masterly study of this fauna by the illustrious Cuvier gave an incredible impulse to geology. One striking characteristic of this fauna was the great predominance of tapirlike animals. Of fifty species of mammals found here, forty species were of this general kind. The most celebrated of these remains are the *Paleothere* (Fig. 342) and the *Anoplothere*. The Paleothere was a three-hoofed animal allied to the tapir, and perhaps connecting with the horse family. The Anoplothere, on the contrary, was a two-hoofed animal, apparently connecting tapirs with the ruminants. In these two we have the even-toed and the odd-toed hoofed animals almost united. The great bird Gastornis, figured on page 375, was found here.

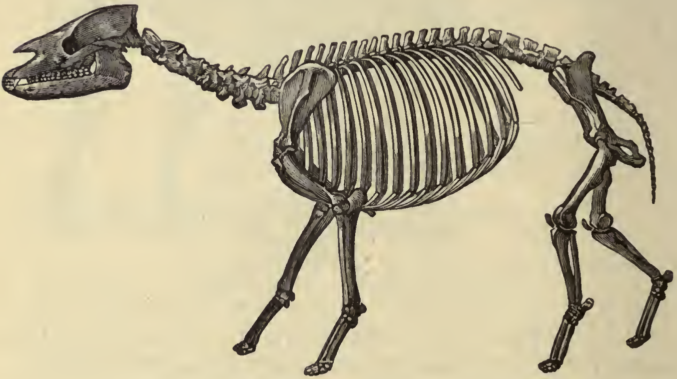

FIG. 342.—Paleotherium magnum, × $\frac{1}{25}$. (After Gaudry.)

It is probable that during the Eocene the Paris basin was the place of an estuary, and the bodies of animals of that epoch were washed down by a river and buried in sediments at its mouth.

In the European Miocene great numbers of remains have been found. Corresponding with the Miohippus and perhaps the Protohippus of the United States, was the graceful tridactyl horse (Hipparion), represented in Fig. 343. The most remarkable animal of this time was the huge *Dinothere*, the earliest of the Proboscidians. It had a proboscis, but not yet developed to the size and strength which this organ attained in the mastodon and the elephant. The singular form of the head is shown in Fig. 344. True monkeys were introduced in the Miocene, and that most destructive of carnivores, the saber-toothed tiger (*Machairodus*), in the Pliocene, though the genus culminated in the Quaternary (see Fig. 356, page 402).

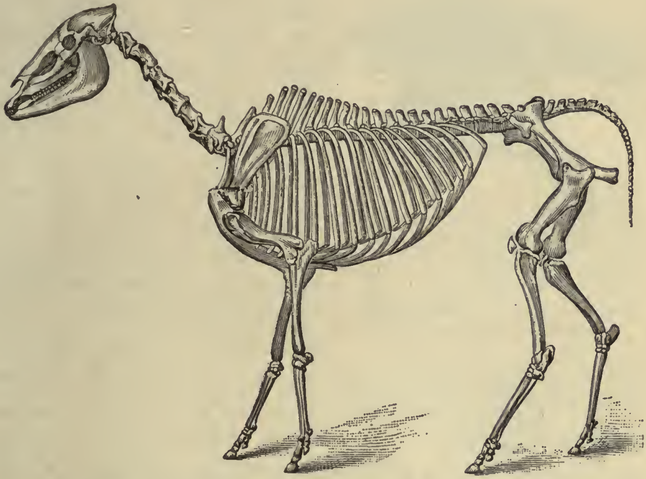

Fig. 343.—Skeleton of Hipparion gracile, restored. (After Gaudry.)

Some General Observations on the Tertiary Mammals; Genesis of Mammalian Orders and Families, etc.—We have already said that in the earliest Eocene, the great branches of the mammalian class were very near together, though their point of union has not yet been found. As time went on, these separated more and more widely, and gave off sub-branches, which again divided, and so on. In general terms, it may be said that some of the *existing orders* may be traced back to the Eocene. Many of the existing *families* commenced in the *Miocene; existing genera* in the *Pliocene;* but existing *species* only in the *Quaternary.* This is well illustrated by one great branch, the *Ungulates,* or hoofed animals. These consist now of many widely separated sub-branches; but in the earliest Tertiary they seem to unite into one, a primal ungulate. As we go up, this branch separates, even in the Upper Eocene, into *odd-toed* (perissodactyls) and *even-toed* (artiodactyls) ungulates. In the Miocene, each of these again separates, the *former* into the elephant *family* (Proboscidians) with five toes, the tapir and rhinoceros families with three toes, and the horse family, with three toes passing into *one;* the *latter* into the hog and hippopotamus families with four toes, and the ruminant family (horned animals) with two toes.

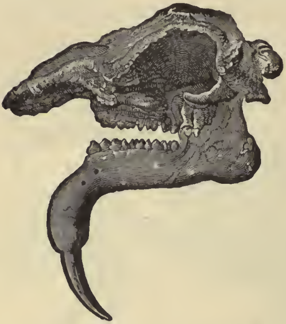

Fig. 344.—Head of Dinotherium giganteum, greatly reduced.

Genesis of the Horse.—Let us trace one of these branches throughout. We select for this purpose the *horse.* A most wonderful series representing this family, about forty species in all, has been furnished by the American Tertiaries, and the successive steps traced by Professor Marsh. First of all, in the early Eocene Wahsatch beds, we find the Eohippus (dawn-horse). This little animal (the size of a fox) had three toes on the hind-foot, and four perfect toes and a fifth splint, and perhaps dew-claw, on the fore-foot. Next, in the Middle

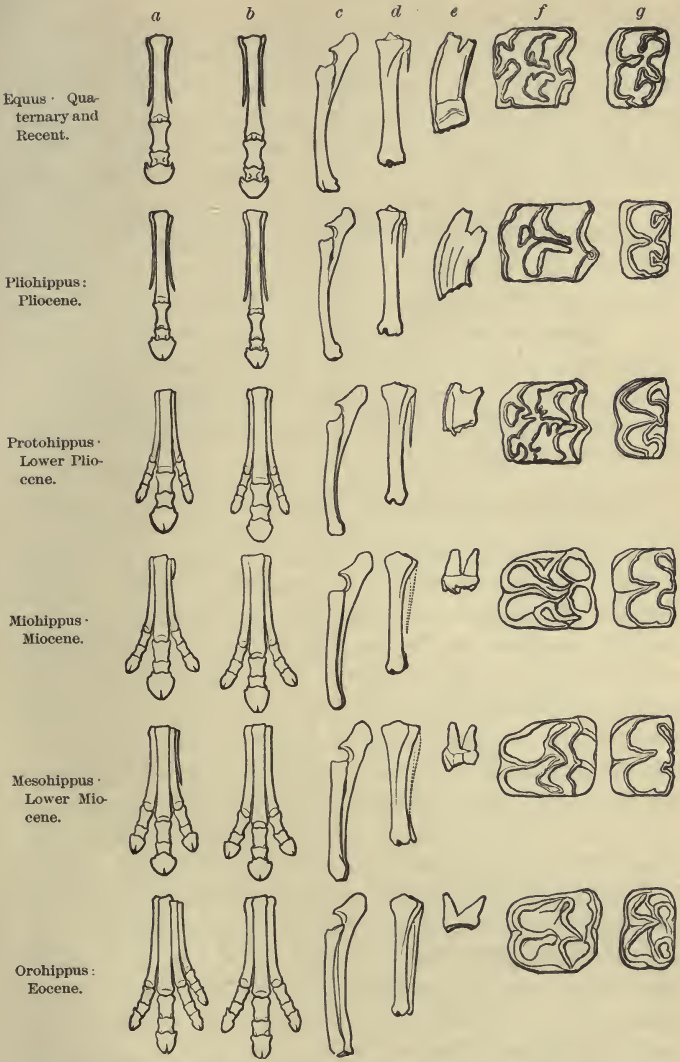
a
b
c
d
e
f
g
Equus: Quaternary and Recent.
Pliohippus: Pliocene.
Protohippus: Lower Pliocene.
Miohippus: Miocene.
Mesohippus: Lower Miocene.
Orohippus: Eocene.

FIG. 345.—Diagram illustrating gradual changes in the horse family. Throughout, *a* is fore-foot; *b*, hind-foot; *c*, fore-arm; *d*, shank; *e*, molar on side-view; *f* and *g*, grinding surface of upper and lower molars. (After Marsh.)

Eocene, came the Orohippus, about the same size, with three toes behind and four in front—the fifth splint being dropped. Next, in the Miocene, came the Mesohippus and the Miohippus (about the size of a sheep), with three toes behind and in front, but the fourth toe of the Orohippus still retained as a useless splint. In these the horse family may be said to be fairly established. Then, in the Lower Pliocene, came the Protohippus, about the size of an ass, with three toes on all the feet, but the two side-toes shorter, and the mid-toe larger, than before. Then, lastly, in the uppermost Pliocene, come the Pliohippus and Equus, in which the side-toes are reduced to useless splints, and the middle toe is greatly enlarged. This is the case in the *modern horse;* its side-splints attest its *three-toed ancestry.*

Crust-Movements during and closing the Tertiary Period.

Remember that, during the Cretaceous, a great sea covered the whole of the Plains and Plateau region, dividing the continent into two continents. By the gradual elevation of the region, this sea was obliterated and replaced by great lakes. The formation of these lakes inaugurated the Tertiary. The elevation of the same region continuing, these Tertiary lakes were successively obliterated, and the prodigious general erosion and cañon-cutting of this region commenced.

On the Pacific border, at the end of the Miocene, the Coast Range of California and Oregon was born. From the beginning of the Cretaceous, the place of this range had been marginal sea-bottom receiving sediment. At the end of the Miocene, these yielded to horizontal pressure, were crushed together, and swelled up into this great range. Probably at the same time occurred the great lava-flood of the northwest, described on page 218.

On the Atlantic border the changes were far less remarkable. There was, however, a gradual increase of the land along the border, until, at the end of the Tertiary, the continent was finished, except the southern part of Florida and its keys, and a very narrow strip along the Southern coast generally. The southern point and the keys of Florida are still growing (see page 111).

Section II.—Quaternary Period.

This is one of the most interesting and yet most difficult portions of the history of the earth. It is the last period preceding and preparatory to the *present.*

Characteristics.—The grand characteristic of this period is the occurrence of wide-spread up-and-down *movements of the earth's crust* in high latitudes or circumpolar regions north and south, attended with *great changes of climate* from extreme rigor to temperateness, and consequent *great changes in species.* Also, the age of mammals seems to culminate here, and man appears on the scene, and was doubtless an important agent among others in bringing about the change of species. Nearly all the invertebrate species and some mammals of the Quaternary are still living. A small percentage of the present mammalian species, man among the number, commenced here (see Fig. 325, page 364).

Subdivisions.—The Quaternary period is divided into two epochs, founded upon the attitude of the land and the changes of climate. These are—1. *Glacial.* 2. *Champlain.* The Glacial epoch was characterized by *upward* crust-movement in high-latitude regions, until the land there stood 2,000 to 3,000 feet higher than now, was *sheeted with ice,* and an Arctic rigor of climate extended in America almost to the shores of the Gulf. The Champlain epoch was characterized by a *downward* movement in the same region until the land was 500 to 1,000 feet lower than now, so that many lower parts of the continent were *covered with sea;* and by a *moderation of tem-*

perature, a *melting of ice*, and a *flooding of lakes and rivers*. It was therefore a *flooded epoch*. Loosened icebergs floated over the flooded seas and lakes. It was therefore, also, an epoch of the reign of icebergs. From this condition the crust gradually rose again to the present condition of things.

Similar changes seem to have occurred everywhere in high-latitude regions, but we are not sure that they were absolutely contemporaneous. Therefore it will be best to take the whole series of changes right through for each locality. We commence with the Eastern United States, because it has been best studied there.

QUATERNARY IN EASTERN NORTH AMERICA.

1. *Glacial Epoch.*

The Drift.—The phenomena now about to be described are extremely varied; but, as they exist all over the Northern United States, we insist that every one observe for himself. What we say is meant *only as a guide*.

All over the northern portion of our country, from 38° to 40° latitude northward, mantling over hill and dale, over mountain and valley, is found a peculiar deposit or soil composed of a heterogeneous mixture of earth, gravel, pebbles, and rock-fragments of all sizes. As this material has evidently been *shifted* and sometimes brought from a long distance, it is called *Drift*. It is impossible to make a description which will apply to all cases, but almost everywhere the lower part in contact with the bed-rock consists of stiff clay with disseminated stones rounded or partly rounded, and *scratched* (Fig. 346). This is called the *stony-clay* or *bowlder-clay*. It is exactly like the ground moraine of a glacier, mentioned on page 58. In places are found heaps or dumps of loose materials similar to the top moraine of glaciers. In places the materials may be irregularly stratified and cross-laminated, as if by water running beneath, or from the snout of a glacier. In places the laminæ may be twisted and crumpled, as if by a glacier pushing along on a mud surface. In still other places, especially west of the Appalachian, the upper part is more widely stratified. But this may belong to a later epoch (Champlain).

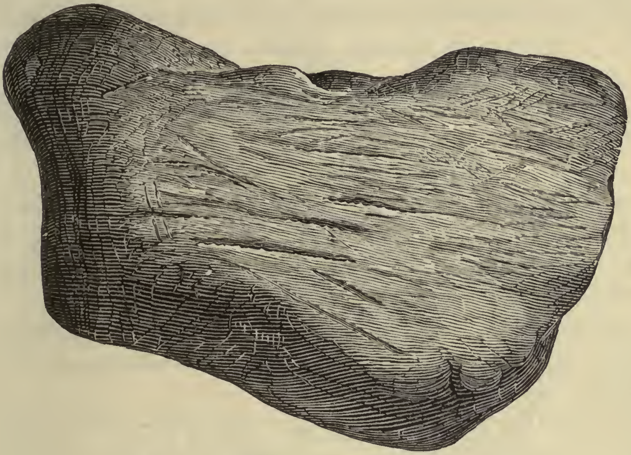

FIG. 346.—Subangular stone. (After Geikie.)

Bowlders.—Over all are scattered rock-fragments and bowlders, of all sizes, both angular and rounded—sometimes as thick as hailstones after a storm, and actually cumbering the earth. These bowlders, whether imbedded in drift or scattered on the surface, are usually entirely different from the country-rock. Great blocks, of thousands of cubic feet, are often seen perched where they do not belong, as if stranded by glacier or iceberg. The parent ledge from which they were torn can often be found, and thus the direction of their transport is known. By this means it has been ascertained that from the Canadian highlands the material has been carried southeastward, southward, and southwestward. The distance carried has been in some cases several hundred miles.

Bed-Rock Surface.—Wherever the drift-mantle is removed, the bed-rock underlying is found to be *glaciated,* i. e., it presents a smooth, billowy surface, scored with straight parallel marks, precisely like the pathway of a glacier, described on page 61. The general direction of these marks is the same as that of the transport of the bowlders, viz., southeast, south, and southwest.

Southern Limit of the Drift; Ice-Sheet Moraine.—The most characteristic of the phenomena described, viz., the stony clay, the glaciated bed-rock, and the great bowlders, extend over the whole northern portion of the continent, down to about 38° to 40° north latitude. Along this southern limit are found remnants of the *terminal moraine of the ice-sheet.*

Its position is marked on the map by the *strong* line. Within this, and marked on the map by the dotted lines, another and later and far distincter terminal moraine is seen sweeping about the Great Lakes and westward in huge festoons (Fig. 347).

Explanation.—The simplest explanation of these facts is, that during this epoch the whole northern part of the continent was elevated, so that the Canadian highlands were 1,000 to 2,000 feet above its present level, and completely covered with an ice-mantle several thousand feet thick, as Greenland and the Antarctic Continent are today. This ice-mantle, covering everything except perhaps the highest peaks, moved southeastward, southward, and southwestward, scoring the whole surface of the country in its path, and accumulating bowlders and earth beneath it. At its limit, represented by the strong line seen on the map, the accumulations, being more abundant, formed a moraine. After a while, the ice-limit, by melting, went northward, dropping bowlders in its course to or perhaps beyond the lakes, but again advanced, and formed the deeply lobed moraine marked by the dotted lines.

We have given only the limit of the general ice-sheet. But in mountain-regions, e. g., in Colorado, and perhaps in Virginia, even beyond this limit, there were great separate glaciers, occupying the valleys, as shown by the moraines left by them. The tracing of the course of these old glaciers by their glaciated pathways, perched

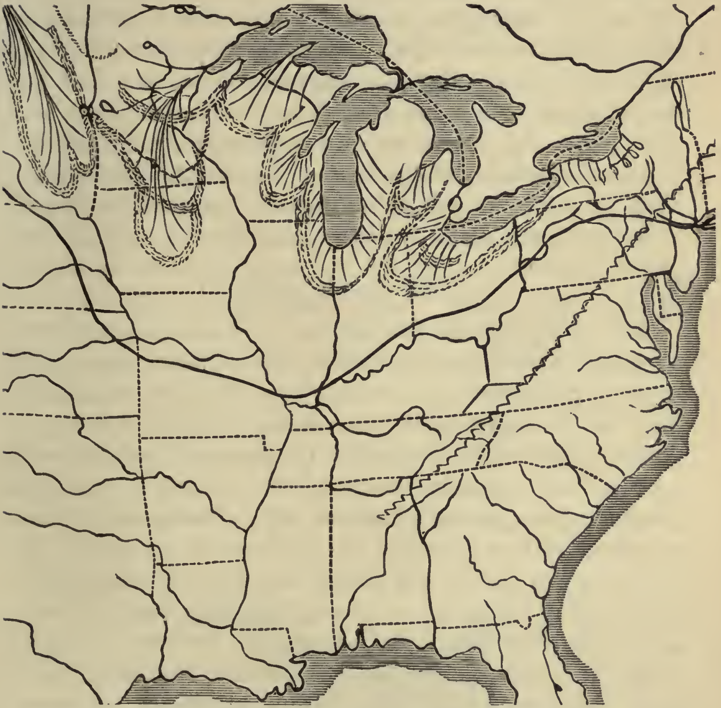

FIG. 347.—Map showing limit of the drift and the second ice-sheet moraine. Limit of northern drift represented by heavy line from Long Island to Minnesota; second ice-sheet moraine represented by triple dotted line.

bowlders, and terminal and lateral moraines gives a fascinating interest to travel among these mountains.

Contrast of Northern and Southern Soils and Rock-Surfaces.—Nothing can be more striking than the contrast between the soil and underlying rock-surfaces within and beyond the limits of the Drift. Within these limits the covering is a heterogeneous mass of shifted material lying on *sound* rock; south of this limit the soil is stratified, and in many places graduates into the rock beneath from which it has been formed by rotting *in place.* Again, the underlying rock in drift-regions is *glaciated,* i. e., smooth, *moutonnéed,* scored; beyond the drift-region there is either no distinct surface to the rock, or else, if there be, it is a rough, weathered surface.

2. *Champlain Epoch.*

At the end of the Glacial epoch, when the condition of things was such as described above, there commenced a crust-movement in a contrary direction, by which the land in the same region was brought downward 100 to 500 or 1,000 feet below this present level, and the lower parts of the continent became covered with the sea. It was therefore a *period of inland seas.* The movement was attended with moderation of temperature, by which the ice-sheet was melted and progressively retired northward. The melting ice produced flooded lakes and flooded rivers. It was therefore also a *flooded period.* Icebergs, loosened from the northern ice-foot, floated over the inland seas and the great flooded lakes, dropping *débris.* Some of the great bowlders are probably to be accounted for in this way. It was therefore also a period of *iceberg agency.* The evidences of this condition of things are found in old elevated sea-margins, lake-margins, and old river flood-plain deposits.

Sea-Margins.—Elevated sea-beaches are found in all countries affected with the Drift. The *highest one* marks the level in the Champlain period. In southern New England it is 50 feet high, in Maine 100 feet high, on the Gulf of St. Lawrence and Labrador 500 feet, and in Greenland 1,000 feet high. The old sea-line may be traced on both sides of the St. Lawrence River, and thence around Lake Champlain nearly 500 feet high, showing that there was a wide bay or sound in this region. It is this which gives name to the epoch. On the bench marking the sea-level about Lake Champlain have been found not only many marine shells, but also the skeleton of a stranded *whale.*

Lake-Margins.—About all the Great Lakes are found now many terraces or benches rising one above another, the highest marking the greatest extent of the lake. About Ontario the highest is 500 feet; about Lake Erie, 250 feet; about Lake Superior, 330 feet. These lakes doubtless at that time ran together, forming a vast sheet of water which drained southward through the Mississippi River into the Gulf. At the same time an enormous lake covered the region about Lake Winnipeg and drained through the Minnesota River into the Mississippi. This ancient lake has been called Lake Agassiz.

River-Deposits.—The section, Fig. 348, represents in a general way the condition of the rivers in all the drift-region. Beneath the present river-bed, *r*, there is a much

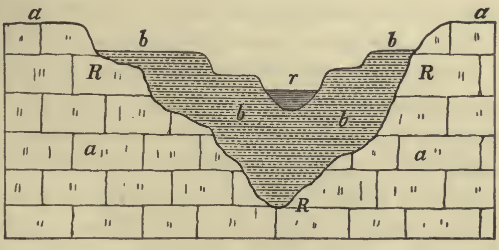

FIG. 348.—Ideal section across river-bed in drift-region.

wider and deeper old river-bed, *R R,* which is filled up often several hundred feet deep with river-silt, *b b,* and into this the river is now cutting its bed. The great river-bed, *R R,* was cut out during the epoch of elevation (Glacial) and previous periods. They are preglacial river-beds. The *filling* was done during this epoch of subsidence (Champlain). The river since then has again cut down, but not so deeply. All the rivers in the drift-region, therefore, are bordered on each side by a wide area of old silt, usually much above the present flood-level, and therefore forming high bluffs or terraces, sometimes one, sometimes many, on each side.

The Cause of the flooded condition was primarily the great water-supply from *melting of the ice-sheet.* But it is evident that the *subsidence of the land* would cause the sea to enter the mouths of many rivers, forming great estuaries ; and also, by diminishing the slope of the river-bed, would tend to increase their floods.

From this subsided condition the land gradually rose again, by successive stages, to the present condition. These successive stages are marked by a succession of sea-beaches, lake-terraces, and river-terraces, below the highest just described. As the land rose, successive sea-margins were left ; the outlet of the lakes also cut deeper and deeper, and drained the lakes to lower and lower levels. Also, all the rivers cut deeper and deeper into the old Champlain silts, leaving them as bluffs and terraces high above the present flood-line (Fig. 348). Sometimes there is but one great bluff on each side, as in the Mississippi River. Sometimes there are several terraces, one above the other, as in the case of the Connecticut River. It is evident that when Lake Champlain was first cut off from the sea by elevation it was a salt lake. It was freshened in the manner explained on page 79.

Quaternary in the Western Part of the Continent.

On the Pacific slope the signs of all these movements are clear; especially are the signs of extensive glaciation magnificent. We shall again vary our mode of presentation by tracing the condition of things throughout the Quaternary in *seas, glaciers, lakes,* and *rivers.* We take seas first, because by this we establish the oscillations.

Seas.—A *more elevated condition* of land than now exists is plainly shown, not only by the boldness of the Western coast and the existence of a line of bold, rocky islands a little way off shore, a recognized sign of a sunken coast, but also by the remarkable fact that remains of the Quaternary mammoth have been found on one of these islands—the Santa Rosa. When this elephant lived, the island was evidently connected with the mainland.

A subsequent *subsided condition* is demonstrated by sea-margins in many places. We shall describe briefly the condition of the sea. At that time the Bay of San Francisco was enormously enlarged; for its waters covered the whole of the flat lands about the bay, including the Santa Clara, Napa, and Sonoma Valleys, and then, passing through the Straits of Carquinas, spread all over the great interior valley of California (Sacramento and San Joaquin), forming an inland sea fifty miles wide and three hundred miles long. The old beach-marks may be traced in many places. Lake Tulare is a remnant of this great inland sea. In Oregon the sea went up the Columbia River, and spread over the Willamette Valley, forming a great sound. From this subsided condition the land *rose again,* making successive terraces down to the present level.

Glaciers.—It is still doubtful if the general ice-sheet extended on this coast as far south as California, although abundant evidences are found in British Columbia; but it is certain that the whole Sierra was at that time covered with perpetual snow, from which ran great glaciers forty to fifty miles long to the valleys below. It is certain that all the valleys and cañons which trench the flanks of the Sierra were filled with glaciers of enormous size. Many of these have been traced in the clearest manner by their *polished pathways,* their *scattered bowlders,* and their lateral and terminal *moraines* (Fig. 349).

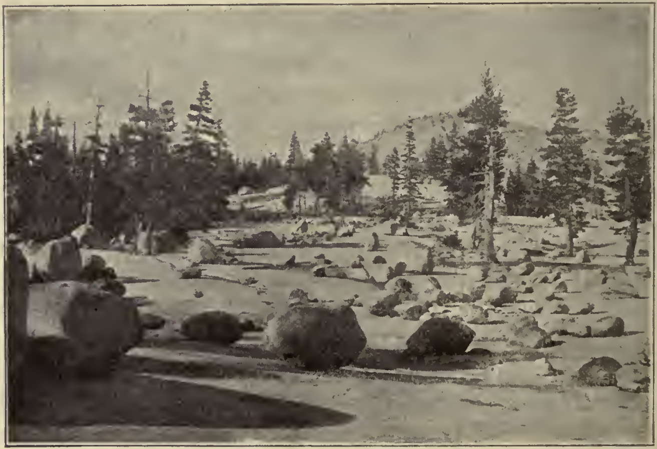

FIG. 349.—Glaciated surface and scattered bowlders near Lake Tenaya, Cal. (From a photograph by J. N. Le Conte.)

Lakes.—All the lakes of that time, especially in the Basin region, were greatly enlarged. About Lake Mono, terraces rise, one above another, to 700 feet above the present lake-level, and inclosing an immense area. The lake-waters then washed against the foot of the Sierra, and glaciers ran into its waters and produced icebergs. At the same time, the whole lower part of the Utah and Nevada basins was filled each with a great lake. That which filled the Utah basin, called Lake Bonneville, was

100 miles wide and 300 miles long. The traveler on the Union Pacific Railway can hardly fail to observe the old terraces, rising up to 1,000 feet above the present lake-level. It drained at that time into the Snake and Columbia Rivers, then lost its outlet, and *dried* away to the remnants—Great Salt Lake, Utah Lake, and Sevier Lake—which we now have. The lake which filled the Nevada basin—*Lake Lahontan*—was of nearly equal size, and its dried-away residues are seen in numerous salt and alkaline lakes, such as Pyramid, Winnemucca, Humboldt, Carson, Walker, etc., which overdot this great area.

Rivers.—The old or preglacial river-beds, on the eastern side of the continent, as we have seen (page 391), *underlie* the present river-beds—i. e., are in the *same place,* but *deeper*. In middle California the relation is quite different and peculiar. Here the old river-beds *overlook* the new—i. e., they are in a different place, and higher. The old river-beds are on the divides between the new. The reason is this: In *middle* California, at the beginning of the Glacial epoch, the old river-beds had already been filled up, first with gravel, and then, by igneous outbursts, with lava. The rivers were thus *displaced,* and began to cut new beds. But at the same time there was a considerable lifting of the whole mountain-region, and consequently the rivers now cut *deeper* than before (Fig. 350). Thus it has come to pass that the new river-beds occupy the places of the old divides,

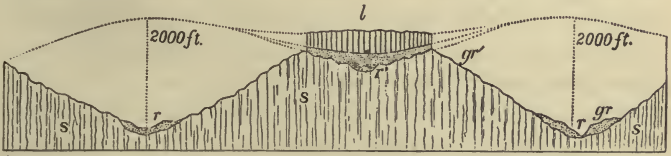

FIG. 350.—Ideal section through two modern river-beds and table-mountain divide: *r′*, old river-bed; *r*, *r*, present river-beds; *s*, slate; *gr*, new gravel; *l*, lava; *gr′*, old gravel under the lava.

and the old river-beds are now found on the top of the present divides.

Phenomena similar to those discussed are found in Europe and in all other high-latitude regions, both north and south of the equator.

Some General Results of Glacial Erosion.

1. **Fiords.**—If one examines an accurate map of coast-lines, he will see that, in the region affected by Quaternary oscillations, there is a bold, deeply dissected coast-line. In Norway these deep inlets are called *fiords,* and therefore this structure, wherever found, is called *fiord-structure.* We find it strongly marked in Greenland and in Alaska. This structure, in Norway, is *partly* due to the action of waves (page 45), but also, and mainly, to the submergence of old glacial valleys. In Greenland and Alaska they are still partly occupied by glaciers.

2. **Lakes.**—Examine your map of North America. See how the whole northern part is dotted over with lakes, while the southern part is almost destitute of them. See also that the lake-area is also the area of the drift. Now, although lakes may be formed in many ways, and exist in all parts of the world, yet undoubtedly the small lakes at least, which are so thickly sprinkled over the drift-region, have been produced by glacial agency.

There are several ways in which glacial lakes were formed: 1. They are sometimes *rock-basins,* scooped out by *glacial erosion.* 2. They are often formed by the damming of drainage waters behind old terminal moraines. These two kinds are thickly strewed all over high mountain-regions in the pathways of old glaciers. Standing on the crest of the Sierra, fifty may sometimes be counted at one view. 3. In flat regions, as in northern Minnesota and British America, they are simply hollows produced by inequalities of deposit of the Drift when the ice-sheet retreated.

Life-System of the Quaternary.

Plants and Invertebrates.—The plants and invertebrate animals were mostly identical with those *still living.* We dismiss these, therefore, with one important remark. Quaternary species are indeed *still living ;* not, however, in the same place, but *much farther north.* This indicated that the climate was much colder in the Quaternary than *now.*

Mammals.—It is only in mammals that we find a striking difference as compared with the present time. Those of the Quaternary are peculiar, differing conspicuously both from the Tertiary and the living species. We shall take our first examples from Europe, as they have been best studied there.

Quaternary Mammals of Europe.—In Europe they are found sometimes in *caves,* where in great numbers and of all kinds they have become entombed ; sometimes on *river-terraces* and old *sea-beaches,* where their floating carcasses have been stranded and buried ; sometimes in *peat-bogs,* where, venturing in search of food, they have mired and perished ; and sometimes, as in Arctic regions, *in frozen soils,* where whole carcasses were sealed up, and are now found perfectly preserved.

The Mammalian Age culminates here.—As already said, the mammalian age seems to culminate in the Quaternary just before its downfall. For example, in England alone, during this time, there lived a great elephant, the mammoth (*Elephas primigenius*), much larger than any now living ; two species of the rhinoceros and one of the hippopotamus ; three species of oxen, two of which were of gigantic size ; a wild horse ; several species of deer, among which were the reindeer and the great Irish elk, a magnificent animal, eleven feet high to the top of its elevated antlers and ten feet between their tips. Of carnivores there were the great cave-bear, larger than the grizzly; a lion and a tiger as large as the African lion and the Bengal tiger; a saber-toothed tiger (*Machairodus*), more formidable than either, with its saber-like tusks projecting six to eight inches beyond the gums; hyenas in great abundance; besides many smaller species. The remains of *man* have also been found associated with these extinct animals.

Mammoth.—This great animal deserves more special mention. During Quaternary times, three great elephants roamed in herds over Europe. The greatest of these—in fact the greatest of all elephants, and the most numerous at this time—was the mammoth (*Elephas primigenius*). The remains of these are found everywhere, but the most perfect in Siberia. Here perfectly fresh carcasses have been exposed by the undermining, by the river, of the frozen bluffs of the river-banks. The one represented here (Fig. 351) is in the Museum of St. Petersburg. The dried skin still remains on the feet and portions of the head. It is known from these carcasses that this elephant was covered with a thick wool, and over this long hair. Unlike living elephants, it was adapted to endure cold. The same was true of the Quaternary rhinoceros, the carcasses of which have also been found preserved in the same way.

Quaternary Mammals in America.—Great mammals were equally abundant in America. There roamed in herds all over this country one species of the mastodon and two species of the elephant, viz., the *Elephas primigenius,* or mammoth, and the *Elephas Americanus.* There were also three or four species of the horse, some of gigantic size; several species of oxen, one of them ten feet from tip to tip of their widely spreading horns; several species of the elk, one of them equal to the great Irish elk, and a great number of gigantic edentates,

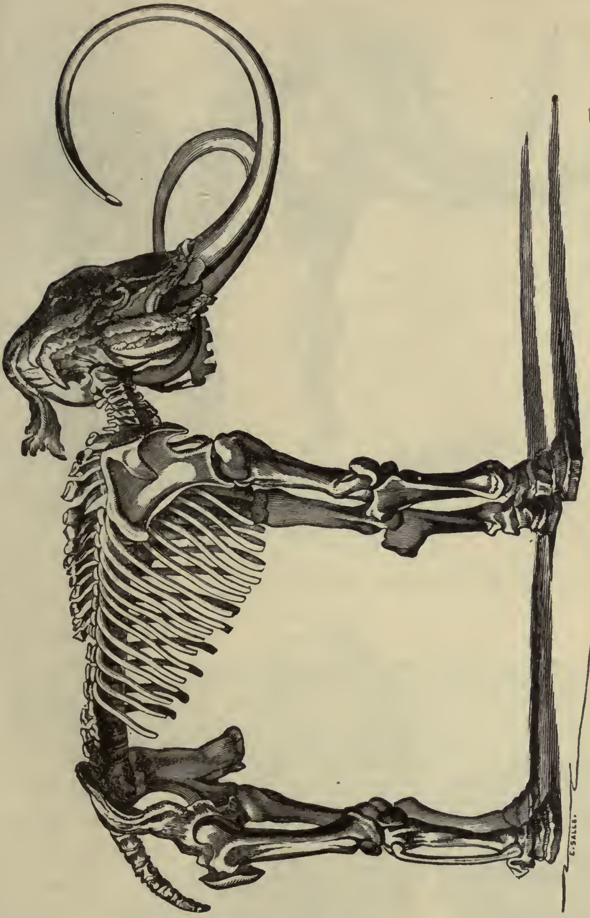

Fig. 351.—Skeleton of the Mammoth (Elephas primigenius). Portions of the integument still adhere to the head, and the thick skin of the soles is still attached to the feet.

ground-sloths, and armadillos. Carnivores were not so abundant as in Europe; but there were several species of the bear, a lion, and a saber-toothed tiger.

The Great Mastodon.—The most perfect specimens of the mastodon have been found in the peat-bogs, where, venturing in search of food, they have become mired.

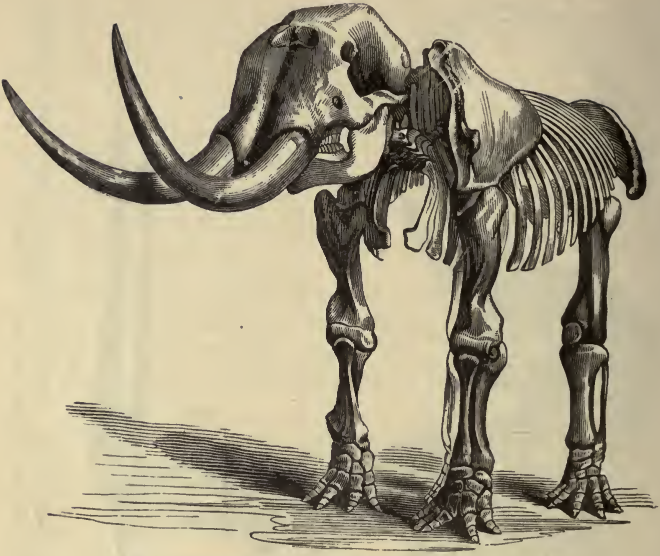

FIG. 352.—Mastodon Americanus. (After Owen.)

In Fig. 352 we give one of the most perfect of these. Any one can distinguish the remains of the mastodon from those of the mammoth, if the jaw-teeth be preserved. The difference is shown in Figs. 353, 354. It is doubtful which of these two animals was the greater; but either

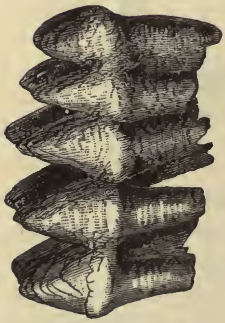

FIG. 353.—Tooth of Mastodon Americanus.

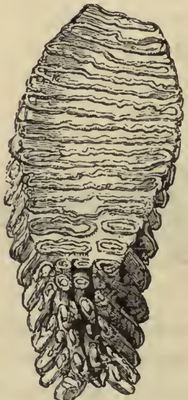

FIG. 354.—Molar tooth of a Mammoth (Elephas primigenius), grinding surface.

was probably more than twice the bulk of the greatest living elephant.

Quaternary Mammals in South America.—We shall mention here only the most characteristic. South America now is characterized by sloths, armadillos (edentates), and llamas. In Quaternary times it was similarly characterized, but the species were *gigantic*. Great ground-sloths and cuirassed animals allied to the armadillo, but bigger than an ox, had their homes in South America, but wandered northward into North America as far as California and Pennsylvania. Among the ground-sloths, the best known are the Megatherium (great beast) and the Mylodon. The hugest of these was the Megatherium (Fig. 355). This was as big as a rhinoceros, and had thigh-bones several times the bulk of those of an elephant. The massiveness of the hind-legs, the hip-bones, and the tail, together with the long arms and prodigious hands, seem to indicate that the animal had the power of standing on its hind-legs while it reached up to tear down branches of trees and feed upon them.

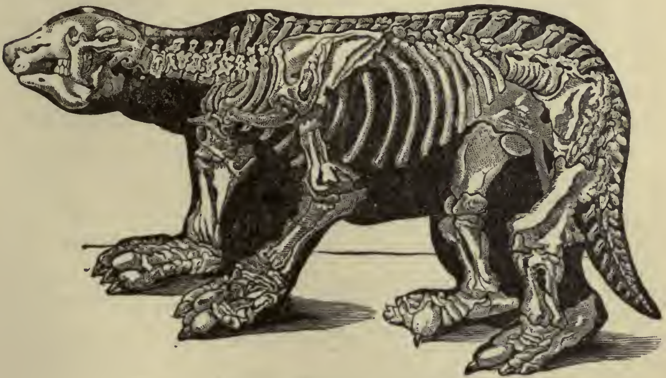

Fig. 355.—Megatherium Cuvieri.

Among the cuirassed edentates, the best known is the Glyptodon, the shell of which was at least five feet long;

but other genera have been found much larger, one as big as a rhinoceros, and another as big as an ox. The saber-toothed tigers were also abundant in South America at this time (Fig. 356).

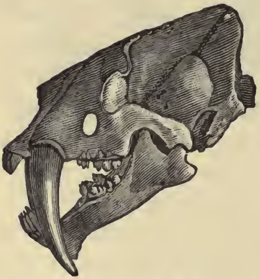

FIG. 356.—Head of Machairodus (smilodon) necator, × $\frac{1}{10}$. (After Burmeister.)

Quaternary Mammals of Australia.—At the present time the mammals of Australia are all *marsupials*. So was it also in Quaternary times; but the species were, again, gigantic. The Diprotodon, for example, was a kangaroo as big as a rhinoceros. Many other gigantic species are also found.

We see, then, that the present distribution of mammalian forms was already established in the Quaternary, but everywhere the species were gigantic.

Some Important General Questions.

1. **Cause of the Cold of the Glacial Epoch.**—The intense cold which characterized the Glacial epoch may have been due to terrestrial or to cosmical causes. It seems right that we should, as far as possible, account for it by terrestrial causes, and resort to the other only if these fail. Now, *northern elevation* would probably produce great cold in the northern hemisphere. This, then, is certainly a probable cause. But the effect has seemed so great and widespread that many think this cause insufficient, and have therefore looked abroad for extra-terrestrial or for cosmical causes. Among the many causes of this kind which have been proposed, the only one which has attracted much attention is that brought forward by Mr. Croll, which attributes it to slow changes in the form and position of the earth's orbit.*

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* For a discussion of this subject, see "Elements," p. 575.

2. Migrations during the Glacial Epoch and their Effect on the Geographical Distribution of Organisms.—The oscillations of the earth's crust during glacial times produced great changes in Physical Geography, elevation enlarging and subsidence diminishing the area of the continents. In this manner gateways were opened *permitting* migrations from one continent to another, as for example between North America and Asia through Bering Straits, and between Europe and Africa through the Mediterranean. Again, the great changes of climate from subtropical mildness to extreme arctic rigor, and back again to temperateness, *enforced* migrations southward and northward, perhaps several times. These migrations, whether permitted or enforced, produced a mixing of different faunas and floras on the same ground; and the severe competitive struggles among them, together with the great changes of climatic conditions, caused many changes, partly by extinction and partly by modification. After these migrations, minglings, struggles, and consequent modifications, the resulting faunas and floras were again in many cases reisolated in their new homes by subsidence. In these isolated new homes they have undergone slow changes by evolution until the present time. Thus have come about the present geographical faunas spoken of in chapter iii., section 4, of Part I. (P. 118). Now, as the Glacial epoch is a comparatively recent geological event, it is evident that the migrations of that time furnish a key to the present distribution of organisms; and conversely, the present distribution of organisms is a key to direction of migrations during that time. We give a few striking examples illustrating this very interesting subject, and completing the explanations given in Part I.

1. **Alpine Species.**—It is a curious fact that alpine species of plants and insects (i. e., species which live on mountains near the *snow line*) are very similar in all parts

of the world (as for example in North America and Europe), although they are so far separated from one another and completely isolated. It must be observed, however, that they are also very similar to *Arctic* species. The explanation is found in the migrations of the glacial times. At that time Arctic species were pushed southward on both continents—to the shores of the Mediterranean in one and of the Gulf of Mexico in the other. On the return of a temperate climate most of them followed the retreating ice-foot back to their Arctic home; but some followed arctic conditions upward to the tops of high mountains, and *were stranded there in alpine isolation* till now. It is true they have been slowly changing since then—some in one direction, some in another—in accordance with a universal law in the case of isolated species; but the time has been too short to effect any great changes.

2. **South Africa.**—Africa, south of Sahara, is inhabited by two very distinct groups of mammals. The first group consists of small animals of very low organization, such as insectivores, but very different from those found anywhere else. These we shall call *indigenes.* The other group consists of very large and highly organized animals, mostly also peculiar to Africa, but similar in general character to those found in Eurasia, especially those of Pliocene times. These we shall call *invaders.* Now, before glacial times, Africa was isolated from the rest of the world and inhabited by the indigenes only. Then came the glacial elevation, opening gateways through the Mediterranean and into Africa, and the glacial cold driving the Pliocene mammals southward into Africa, where they were shut up by the closing of the passages through the Mediterranean and by the formation of the Desert of Sahara. The subsequent struggles between invaders and indigenes, and the effect of a new environment on the invaders, have greatly changed both, but

especially the weaker indigenes. Thus have resulted the mammalian fauna of Africa.

3. **The British Isles.**—The fauna and flora of the British Isles are almost identical with those of Europe, but not quite. They differ in two respects. *a.* There are *varietal,* though perhaps not *specific,* differences of form. *b.* The number of species is much less than on the continent. This is especially true of Ireland. Thus, of 90 species of European mammals only 40 are found in England and 22 in Ireland. Of 22 European species of reptiles and amphibians only 13 are found in England and 4 in Ireland. The migrations of glacial times completely explain this. Before glacial times Great Britain was a part of Europe and had the same fauna and flora. During the glacial times it was covered with the ice-sheet, and all life destroyed or driven southward. After the glacial times it was still connected with the continent, and began to be recolonized by migration from Europe. But *before the colonization was completed,* especially for more distant Ireland, it was again separated by subsidence from the continent, and at the same time Ireland was separated from England. The time since has not been sufficient to make species, although it has been enough to make incipient species, i. e., geographical varieties.

4. **Coast Islands of California.**—The flora of California consists of two groups of species, the one characteristically Californian, the other more widely diffused. The first is undoubtedly indigenous, the second is probably composed of invaders from the north. Now, off the coast of Southern California there is a string of bold, rocky islands about 2,000 feet high and separated from the mainland by a deep channel 50 miles wide. The flora of these islands is very peculiar. Of 300 known species about 50 are wholly peculiar to the islands and not found elsewhere in the world. The remaining 250 are all characteristic California species. Now the explanation.

Before and during the early part of the Glacial epoch the islands were a part of the continent. We have already given proof of this on page 393. At that time all was inhabited by the same flora, viz., the indigenous. Before the invasion from the north the islands were separated from the mainland. Then came the northern invasion and consequent struggle between native and invading species—the destruction of some natives and the modification of others—and the final result was the California flora as we now know it. But the island flora was spared this conflict, and therefore retained more nearly the original character of both. In the flora of these islands, therefore, we see a near approach to the flora of both mainland and islands before the separation.

CHAPTER VI.

PSYCHOZOIC ERA.—AGE OF MAN.

In all previous ages there ruled brute force and ferocity. In this age alone Reason appears as ruler. The order of Nature must be adjusted to this keynote. Therefore, the great ruling mammals of the previous age must become extinct, and the mammalian class must become subordinate; noxious animals and plants must diminish, and useful ones be preserved.

Although in length of time this is not to be compared to an era, nor to an age, nor to a period, nor even to an epoch, yet it deserves to be made one of the primary divisions of time, not only on account of the dignity of man, but also, and mainly, because through his agency there is now going on in organic forms a change as sweeping as any which has ever taken place. This change has been going on ever since the introduction of man, and is going on now, but will not be complete until civilized man occupies the whole earth.

It is interesting to mark some of the steps of this change. The disappearance of the mammoth, the mastodon, the cave-bear, and the saber-toothed tiger was due, partly at least, to man. These are among the first. Some of the gigantic oxen of Europe (*urus*) lingered until Roman times. One species (*aurochs*) still lingers, being preserved by royal edict in the forests of Lithuania. The bison or buffalo of our Western plains is doomed to speedy extinction, unless saved by domestication. In fact, nearly all our domesticated animals and useful plants have been thus saved.

A remarkable example of recent extinction of the Quaternary species is found in the gigantic wingless birds of New Zealand and Madagascar. The bones of the Dinornis and the Epiornis are very abundant in these islands. The *Dinornis giganteus* (Fig. 357) was twelve feet high. The drumstick was a yard long, and as big as the leg-bone of a horse. A perfect egg of the Epiornis has been found, six times as big as the egg of an ostrich. The extinction of these birds, although it occurred before the discovery of these islands by civilized man, was so recent that the feet have been found with dried skin upon them, and eggs with the skeletons of chicks within.

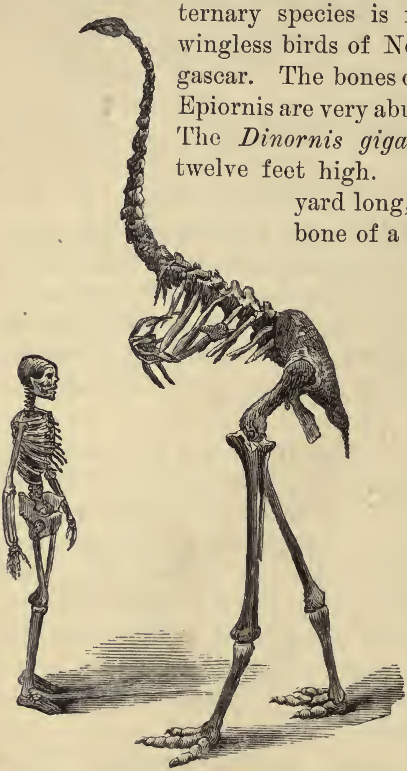

FIG 357.—Dinornis giganteus, × $\frac{1}{36}$. (From a photograph of a skeleton in Christchurch Museum, New Zealand.)

Now, in this gradual change from the Quaternary to the present fauna and flora, *when* did *man* first appear upon the scene and become an agent of change? And *what kind of man* was this *primeval man?* These are questions of transcendent importance.

Antiquity of Man.

On this important question, history, archæology, and geology meet and coöperate; and it is to the introduction of geological methods that we must attribute the rapid advances in recent times.

Archæologists long ago divided the history of human progress, according to the nature of the implements used, into three ages—a *stone* age, a *bronze* age, and an *iron* age. Again, by closer study, they subdivided the stone age into an older stone (*Paleolithic*) and a newer stone (*Neolithic*) age. In the one, the stone implements are chipped; in the other, polished. Again, under the guidance of geology, the Paleolithic has been subdivided into the *mammoth* age and the *reindeer* age. In the former, man was contemporaneous with the mammoth, the cave-bear, and other extinct Quaternary animals; in the latter, the mammoth had nearly disappeared, but the reindeer was abundant over all middle and southern Europe. The flint implements in the former were so rude that they might well be called flint-flakes; in the latter they were carefully chipped. The former was coincident with the Mid-Quaternary, i. e., *Champlain*, or perhaps *Interglacial;* the latter with the second Glacial or the early Post-glacial.

3. Iron age			Psychozoic.
2. Bronze age			
1. Stone age	Neolithic—Domestic animals.		
	Paleolithic	Reindeer—Late Quaternary.	
		Mammoth—Mid-Quaternary.	

As seen by the schedule above, the Psychozoic era and age of man commences with the Neolithic. Before that time, man existed, indeed, but contended doubtfully for mastery with the great Quaternary animals. From that time his victory is assured and his reign begins.

Primeval Man in Europe.

According to our schedule, man is traced back to the Mid-Quaternary. Some geologists think that there are signs of his existence still earlier, viz., in the Tertiary; but the evidence is acknowledged to be unsatisfactory. We shall confine ourselves, therefore, to Quaternary man. We shall commence with Europe, as the evidence is more complete, and all the steps represented.

Quaternary Man; Mammoth Age; the River-Drift Man.—Some twenty years ago, M. Boucher de Perthes found, in the undisturbed gravels of the upper terraces of the river Somme, the implements of man associated with the bones of many extinct Quaternary animals, such as the mammoth, the rhinoceros, the hippopotamus, the hyena, the horse, the Irish elk, the cave-lion, etc. The doubts which were at first entertained by the more cautious geologists have been entirely removed by careful examination. We give this as only one example of very many. In all cases the implements are of the rudest kind of flaked flints, like those figured on page 414.

The Cave-Man.—In Quaternary times, man undoubtedly contested with the hyena, the lion, the saber-toothed tiger, and the cave-bear the right to occupy the caves as homes. The evidence of this is found in the association of his implements, and even his bones, with those of all the extinct carnivores mentioned, under conditions which admit of no doubt of their contemporaneousness. They are sometimes entombed together, and covered with stalagmitic crust, which has never been broken from Quaternary times until rifled by the geologist. We give a single example.

The Mentone Man.—In a cave at Mentone, near Nice, has been recently found the almost perfect skeleton of an old man, of more than average height, lying on his side in an easy position, and about him chipped implements and bones of extinct animals, among which were many pierced reindeer's teeth. All of these were perfectly preserved by a stalagmitic crust. We may well imagine that this old hunter, finding his end approaching, retired to his cave-home, laid himself quietly down, with the implements and trophies of successful chase about him, and gave up the ghost. Good Mother Nature then slowly buried his remains, and sealed them up beneath a crust of stalagmite.

The Primeval Aquitanians.—In southwestern France, on the river Vizère, a branch of the Dordogne, are found many caves which were inhabited by a more peaceful race. They were not only hunters, but also fishers; for we find, besides stone implements, many implements made of bone, among which are rude fishhooks. They also show evidence of some skill in drawing and carving. Among the bone implements found there are many drawings of extinct animals. Fig. 358 represents a rude but very characteristic sketch of a mammoth, made by contemporaneous man. In these caves we find a gradual transition from the mammoth to the reindeer age.

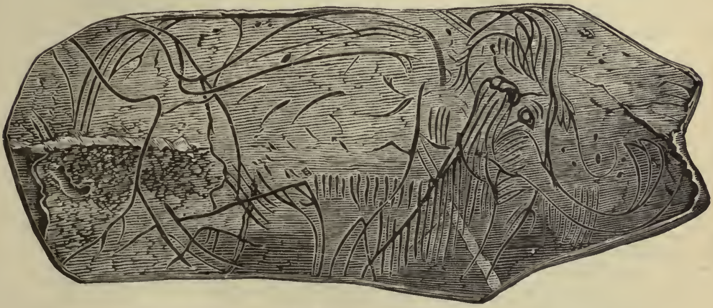

FIG. 358.—Drawing of a Mammoth by contemporaneous man.

General Conclusions.—These all belong to the Quaternary. In Europe, therefore, man certainly saw the flooded rivers and lakes, and probably the great glaciers. He certainly hunted the great extinct Quaternary animals, the mammoth, the cave-bear, the cave-lion, the great Irish elk, and the reindeer. All the evidence points to an extremely low, savage state, with little or no tribal organization. There is no evidence yet of either domestic animals or of agriculture.

Neolithic Man.

Kitchen-Middens; Refuse-Heaps; Shell-Mounds. —In many parts of Europe, especially in Denmark and Sweden, are found mounds, composed wholly of shells and other refuse of tribal gatherings and feastings. The men of that time seem to have had the habit of gathering annually at some place where food was abundant, usually on the seashore, at the mouth of a river. From year to year the refuse of such gatherings accumulated until mounds of great extent were gradually formed. In these mounds are found the bones of men and animals and the implements of men, and from these we may form a good idea of the character and habits of the men.

Here, then, we find a great and somewhat sudden change: 1. There are no longer any extinct Quaternary animals. 2. We find here, for the first time, domestic animals, viz., the dog, the ox, the sheep, etc., and also evidences of agriculture. 3. The implements are no longer only chipped, but are often carefully polished by rubbing. Rude pottery is also found. 4. We have here for the first time the evidence of tribal organization, similar to the savage races of the present day. 5. The conformation of the skull shows a different race from that of the cave and river-drift men. In a word, we have here the appearance in Europe, probably by migration, of a different and higher race. Until this time man in Europe seems to have contended doubtfully with wild animals: now he seems to have established his supremacy. The Psychozoic era and age of man, therefore, rightly commence here, and all that follows may be claimed by archæology and history. Nevertheless, we shall give a very brief sketch of further progress.

Transition to the Bronze Age.

Lake-Dwellers.—In 1850 the lakes of Switzerland became very low, and a great number of wooden piles were exposed. Interest being excited, the same was found to be true of all the lakes of middle Europe. By dredging, implements of war, of the chase, of husbandry, and ornaments and trinkets of all kinds were found in great abundance. Some of these were polished stone, but most were bronze, and often beautifully finished. Remnants of grain and fruits of several kinds were also found. From these findings the houses (Fig. 359), the habits, and the mode of life of this people have been reconstructed, and even a novel embodying their life has been written.*

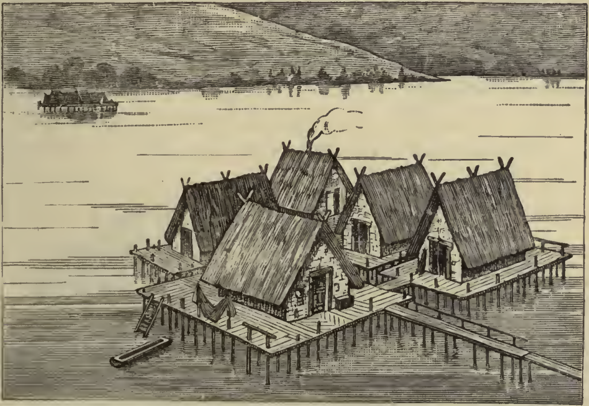

Fig. 359.—Lake-dwellings, restored. (After Mortillet.)

Thus we might continue, by means of remains alone, to trace progress, through Roman graves, Roman roads and implements, etc., to the graves in our own churchyards and the machinery of our own times. This all belongs to history. Thus we trace geology into archæology, and archæology into history.

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* "Realmar," by Arthur Helps.

Primeval Man in America.

It must be remembered that the different men we have described in Europe represent different stages of progress there. The progress has not been at the same rate everywhere, and therefore the different stages are not necessarily contemporaneous. When America was discovered, the native tribes were still in the stone age, and many savages are only in this stage of advance now. The advance was more rapid in Europe, apparently because of the frequent and extensive migrations and conflict of races there. Nevertheless, the rudest state (Paleolithic age) seems to have been nearly contemporaneous in America and Europe, and probably elsewhere.

Quaternary River-Drift Man in America.—There are many examples of rude flint-flakes in the river-gravels of California and in the glacial drift of New Jersey and Ohio. These were, it is believed, the work of a race cor-

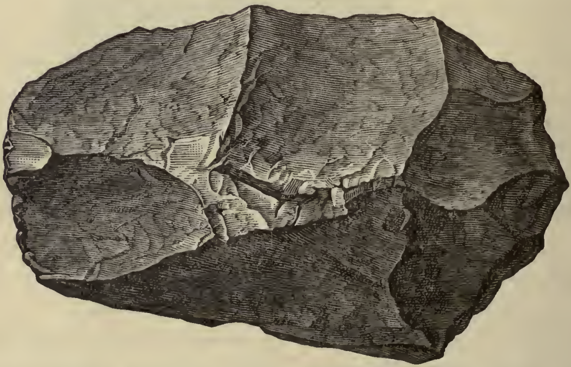

Fig. 360.—Paleolith found by Abbott in New Jersey, slightly reduced. (After Wright.)

responding to and contemporaneous with the river-drift man of Europe (Fig. 360). Some doubts have been recently thrown on the antiquity of these findings. For this reason we will not dwell on Glacial man in America.

Neolithic Man in America.—The Neolithic age is represented here, as in Europe, by *refuse-heaps*, which were evidently made in the same way as those already described, and have similar contents. They are abundant on the seacoasts everywhere, and some of them are probably no older than the discovery of America; for, as already said, the native tribes were then still in the stone age.

Mound-Builders.—The bronze age is probably, though imperfectly, represented by the mound-builders. In many places, especially in the valley of the Mississippi, are found mounds of enormous size, and fortifications and communal houses of somewhat elaborate construction. In connection with these have also been found not only highly polished stone implements, but also implements of hammered copper. The copper-mines of Lake Superior were evidently worked by them, as the old workings have been found. The mound-builders were probably a different race from the hunter tribes of Indians, and more advanced, although many now think they are the same.

Cliff-Dwellers.—In the dry regions of New Mexico and Arizona the almost perpendicular cliffs bordering the *mesas* are studded with remains of many-storied communal houses of stone. There are small remnants of several tribes in that region—Pueblos, Moquis, and Zuñis—that live now in similar dwellings, on the flat tops of almost inaccessible *mesas*. One dwelling with many rooms is occupied by a whole community. These also are entirely different from the roving tribes, and by many are connected with the Aztecs on the one hand, and the mound-builders on the other.

It is needless to repeat that these last three heads belong to the present epoch.

Conclusions.

1. We have thus traced man back to the Mid-Quaternary. It is possible that he may hereafter be traced still further back; but this seems very improbable. No mammalian species now living can be traced further back than the Quaternary. Man belongs to the present mammalian fauna, and probably came in with other mammalian species in the Quaternary.

2. We have not yet been able to find any undoubted transition forms or connecting links between man and the highest animals.* The earliest known man, the river-drift man, though in a low state of civilization, was as thoroughly human as any of us.

3. The amount of time which has elapsed since man first appeared is still doubtful. Some estimate it at more than a hundred thousand years—some only ten thousand. The question should not be regarded as of any importance, except as a question of science.

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* Such a link is supposed, by many, to have been recently found in Java, and named Pithecanthropus. We wait for more evidence.

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